PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

FEDERAL WORKS AGENCY
PUBLIC ROADS ADMINISTRATION

VOL. 22, NO. 6 AUGUST 1941

CUTTING A SAMPLE OF ASPHALTIC CONCRETE PAVEMENT IN OHIO

For sale by the Superintendent of Documents, Washington, D. C. See page 2 of cover for prices

PUBLIC ROADS ▸ ▸ ▸ *A Journal of Highway Research*

Issued by the

FEDERAL WORKS AGENCY

PUBLIC ROADS ADMINISTRATION

D. M. BEACH, *Editor*

Volume 22, No. 6 — August 1941

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

In This Issue

THE PUBLIC ROADS ADMINISTRATION - - - - - - - - - Willard Building, Washington, D. C.

REGIONAL HEADQUARTERS - - - - - - - - - - - - - - - - Federal Building, Civic Center, San Francisco, Calif.

▼

DISTRICT OFFICES

DISTRICT No. 1. Oregon, Washington, and Montana.
Post Office Building, Portland, Oreg.

DISTRICT No. 2. California, Arizona, and Nevada.
Federal Building, Civic Center, San Francisco, Calif.

DISTRICT No. 3. Colorado, New Mexico, and Wyoming.
254 New Customhouse, Denver, Colo.

DISTRICT No. 4. Minnesota, North Dakota, South Dakota, and Wisconsin.
1109 Main Post Office Building, St. Paul, Minn.

DISTRICT No. 5. Iowa, Kansas, Missouri, and Nebraska.
729 U. S. Courthouse, Kansas City, Mo.

DISTRICT No. 6. Arkansas, Louisiana, Oklahoma, and Texas.
Room 502, United States Courthouse, Fort Worth, Tex.

DISTRICT No. 7. Illinois, Indiana, Kentucky, and Michigan.
South Chicago Post Office Building, Chicago, Ill.

DISTRICT No. 8. Alabama, Georgia, Florida, Mississippi, and Tennessee.
Post Office Building, Montgomery, Ala.

DISTRICT No. 9. Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont.
76 State St., Albany, N. Y.

DISTRICT No. 10. Delaware, Maryland, Ohio, Pennsylvania, and District of Columbia.
Willard Building, Washington, D. C.

DISTRICT No. 11. Alaska.
Room 419, Federal and Territorial Building, Juneau, Alaska.

DISTRICT No. 12. Idaho and Utah.
Federal Building, Ogden, Utah

DISTRICT No. 14. North Carolina, South Carolina, Virginia, and West Virginia.
Montgomery Building, Spartanburg, S. C.

Because of the necessarily limited edition of this publication it is impossible to distribute it free to any person or institution other than State and county officials actually engaged in planning or constructing public highways, instructors in highway engineering, and periodicals upon an exchange basis. At the present time additions to the free mailing list can be made only as vacancies occur. Those desiring to obtain PUBLIC ROADS can do so by sending $1 per year (foreign subscription $1.50), or 10 cents per single copy, to the Superintendent of Documents, United States Government Printing Office, Washington, D. C.

ACCIDENT HAZARD AT GRADE CROSSINGS

A RATING BASED UPON RAILWAY AND HIGHWAY TRAFFIC, TYPE OF PROTECTION, AND PHYSICAL CHARACTERISTICS OF THE CROSSING

BY THE DIVISION OF HIGHWAY TRANSPORT, PUBLIC ROADS ADMINISTRATION

Reported by L. E. PEABODY, Senior Highway Economist, and T. B. DIMMICK, Associate Highway Engineer-Economist

HIGHWAY ENGINEERS have been attempting for some time to develop a method of measuring the need for railroad-highway grade crossing separation or protection, and of stating this need in the form of a numerical rating. Many plans, founded on studies of the various basic relationships, have been proposed. Generally, the rating has been reached by assigning coefficients to various factors connected with the individual crossing and inserting these coefficients in a formula. Because the coefficients chosen were frequently the result of estimates, the ratings have often lacked uniformity and were sometimes thought to be biased.

Methods of measuring the need for highway-railroad grade crossing separation or protection have long been sought by highway engineers. Formulas have been advanced in which coefficients have been assigned to various factors connected with the individual crossing.

A large amount of information, collected by the various highway planning surveys in all sections of the country concerning rural grade crossings at which accidents had occurred, was used (1) in calculating protection coefficients for various types of crossing protection, and (2) in evaluating the relative accident hazard at crossings.

Hazard ratings are particularly valuable in obtaining the maximum of hazard reduction, either through crossing protection or elimination, for a given expenditure. They may be quickly calculated by graphical methods; and the hazard rating is a valuable means of selecting crossings that should receive priority in treatment. Local conditions at the crossing are shown to be of considerable importance.

Elimination or protection of railroad grade crossings should not depend solely upon the inherent hazard of the crossing itself. A priority program made up on such a basis, even if perfect ratings of inherent hazard were available, might result in exhaustion of funds with the separation of a few very dangerous crossings. A wiser distribution of the funds might permit the separation, or protection, of a much larger number of crossings and with an aggregate hazard elimination much in excess of that resulting from the first program. The more valuable measure would be based upon the cost per unit of hazard reduction, and the objective should be the maximum of hazard elimination with a given sum of money.

The total cost of elimination depends in part upon the cost of any adjacent lands that must be acquired, as well as upon the construction expenditures necessitated by the physical layout at the individual crossing. The cost of one separation at a location where land values are high, if distributed over several locations where construction expenditures are smaller and land values are lower, might result in the elimination of a total of many times as much hazard.

RATINGS BASED ON HAZARD TO LIFE AND TIME LOSS

Another factor to be considered in the setting up of such a program is the amount of delay to highway traffic, and resulting economic loss, at a crossing. Where hazard ratings are approximately equal, the crossings used by the larger number of motor vehicles should be selected for elimination, since this will result in a minimum of economic loss due to delay.

The evaluation of objectionable grade crossing features is usually based on one or both of two considerations—the relative potential danger to human life, or the relative loss of time. In considering rural grade crossings it is believed that the hazard to life is more important than the time factor. In rural areas trains move faster and the time loss at crossings will not be as serious a matter generally, although it may be a source of annoyance. The method discussed in this paper deals with the measurement of the hazard at the grade crossings as one means of evaluating the need of separation or protection.

In order to calculate the hazard that exists at any crossing, a large amount of information was collected by the various highway planning surveys in all sections of the country concerning rural crossings at which accidents had occurred: Data concerning 3,563 such crossings were furnished by the planning survey organizations of 29 States. This information consisted of a description or sketch of the crossing, a statement of the highway and railway traffic using the crossing, and a description of the accidents that had occurred in a 5-year period.

The description of the crossing included the clear view distances measured along the tracks from points on the highway 300 feet from the crossing, the gradient of the highway on either side of the crossing, the alinement of the highway at the crossing, the surface type, the number of tracks crossed, the angle of intersection of the highway with the railway, and other special features that might affect the safety of the crossing. Any type of protection that had been installed at the individual locations was described. Data concerning the average daily highway and train traffic were generally subdivided to show the division between passenger-car and commercial traffic on the highways and the division between high-speed, medium-speed, and standing or switching trains, on the railroads. Finally the number of accidents, including the number of persons killed and the number injured, were given and the accident causes which could be determined were reported. This information covered a period of 5 years, generally from 1932 to 1936 inclusive, and furnished a basis for determining the relations between the number of accidents and some of the factors contributing to these accidents.

Several deficiencies in existing accident reports condition the results of this study and should be stated to insure a complete understanding by the reader. Some writers of accident reports ascribed similar causes to accidents which were very different in nature. For example, the reports of one division superintendent stated, with almost flawless uniformity, that the accident resulted from "car stalled on crossing." Other more careful reporters used the same phrase, but differentiated between the motor-vehicle operator who rounds a sharp curve or comes from a sector with short sight distance and is surprised to find a train a short distance away, and other cases to be cited. This operator in panic, kills his motor and does stall his car directly before the approaching train—often with fatal results. Other accidents, generally described as "car stalled on crossing," include cases of drunken drivers who have left their vehicles standing on the crossing, drivers of stolen cars who have abandoned the stalled cars because of fear of apprehension, and the driver who leaves the car standing on the crossing while he goes for assistance to remove it. The case first cited differs fundamentally from the three others. All have actually been found, some frequently, in the accidents reported.

The first case is a true "accident" in the generally accepted meaning of the word. The drunken driver's "accident" is self-induced; the driver of the stolen car suffers no economic penalty from his "accident" and may be indifferent to the possibility of injury or death to those in the train; the driver who leaves the car while he goes for help may either be exercising poor judgment or may actually be unable to push the car alone. However, if the accident reporter records them all as due to "car stalled on crossing" and gives no further detail, the true hazard rating of the crossing is obscured. Failure to differentiate in these cases is not uncommon and has serious unmeasurable effects upon the results of an accident relation study. Other and relatively infrequent causes such as the case of the driver who is convinced he can beat the train over the crossing and shoves down the accelerator, while his passenger is equally convinced that it can't be done and grabs the brake, must be dealt with in the analysis.

There are other difficulties in arriving at the true hazard rating of a crossing. For example, some crossings have been given "over protection" in the sense that the true hazard rating would not justify the kind of protection that has been installed. These cases often result from public demands after some particularly spectacular accident which may have occurred during Christmas holidays or which was accompanied by a fire, as when a gasoline truck is hit. These more or less isolated accidents provoke widespread discussion and criticism and, because of their spectacular nature, often result in the crossing being given a higher type of protection than would generally be thought necessary.

LOCAL CONDITIONS SHOULD TEMPER USE OF FORMULA

The formula for the rating of crossings derived herein is general and does not take completely into account special local conditions that greatly affect the true hazards at a given crossing. It has the advantage of objectivity but does not take into account the effects of some of the specific conditions peculiar to the individual crossing. For example, there are crossings where every train movement is guarded by brakemen who serve as flagmen. These crossings show a statistical movement of a certain number of trains per day; while from the standpoint of true hazard (because of the protection given each train movement), there are actually no trains per day. A crossing of U. S. Route 1 near Laurel, Md., and another crossing of U. S. Route 1 near the Washington Airport between Washington, D. C., and Alexandria, Virginia, are examples of such cases.

Any formula arrived at through use of accident experience must be general in application because of the wide variety of conditions to be met. Nevertheless, a rating of crossings upon a basis of knowledge of local conditions alone is subjective, and suffers from failure to take accurately into account the effect upon the hazard of the amount and type of highway and railway traffic, the protective devices in operation at the crossing, and the physical characteristics of the crossing and its approaches, such as angle of vision, sight distance, number of tracks, grade of approach highways, etc.

Because of the conditions just cited it would seem best to use any formula in conjunction with a knowledge of peculiar local conditions. To be sure, it is difficult to know how much to modify the formula for hazard rating by consideration of local conditions such as those described in detail above. However, a rating of the crossings of a State made upon the basis of the formula may be compared with ratings made independently by several individuals who are well acquainted with local conditions surrounding individual crossings. Priority lists for elimination or protection of crossings arrived at in such fashion will combine the best features of both methods.

Another major problem involved in the derivation of a formula for hazard rating is whether to include or exclude in the analysis, crossings for which no accidents were reported during the period covered by the study. It is possible that at these crossings there may have been an accident, very soon after the close of the period under observation, or there may have been an accident in the period just prior to that for which data were reported. Five years, the period used in the study covered by this report, is a rather short time for the establishment of true accident ratings, and a rating of 0.2 on the basis of 5 years' experience might become a rating of 0.8 on 25 years' experience. Because of this relatively high variability, and the relative shortness of the experience, it was decided to omit from consideration altogether data for crossings at which no accidents were reported within the 5 years studied.

A study was first made of the data submitted to determine the accident trend caused by variations of the various items concerning the crossings. Several of these items are qualitative and suitable preliminary coefficients were determined on a basis of traffic per accident. This study indicated that considering traffic, both highway and train, and type of protection, a definite trend was easily obtainable. Other items, although they probably influenced the safety or hazard at individual crossings, when considered in combination indicated no average trend or one too indefinite to make its use practicable. The results of this preliminary study indicated, therefore, that traffic and protection were the only factors that could be depended upon to rate the crossings on an average accident basis.

Before calculating the preliminary coefficients, all data concerning accidents of the "scratch" type—those resulting from intoxication, and certain of the "car stalled on crossing" type, as previously described, were

eliminated. Accidents such as "striking gates" or "running off crossing plank" were thought to be of minor importance and were excluded from the study being made. The accidents due to drunkenness were eliminated because it was assumed that drivers in that condition were unfit to handle their vehicles and would possibly have had an accident with passing traffic or at some obstacle along the roadside if they had not happened to have the accident at the crossing. A few other accidents of a miscellaneous nature, which were not connected with a train movement, were also eliminated from the study.

PROTECTION COEFFICIENTS CALCULATED FOR VARIOUS TYPES OF CROSSING PROTECTION

As stated above, preliminary coefficients were determined for the various common types of protection by determining the average number of "exposure units" which passed over all crossings of each type of protection for each accident which had occurred at those crossings. The exposure units were obtained by multiplying the average daily highway traffic by the average daily train traffic. These products were divided by 100 to reduce the size of the figure. The equation used in determining the coefficient for each type of protection was as follows:

$$P=\frac{1}{N}\sum\left(\frac{H\times T}{100\,A}\right)=\frac{1}{100\,N}\sum\left(\frac{H\times T}{A}\right)\text{--------}(1)$$

where

P = the protection coefficient for a type of protection,
N = the number of crossings in a type group,
H = the highway traffic at each crossing,
T = train traffic at each crossing, and
A = number of accidents.

Using the above formula the following preliminary protection coefficients were determined:

Type of protection:	*Preliminary protection coefficient*
Signs	19
Bells	29
Wigwag	56
Wigwag and bells	63
Flashing lights	96
Flashing lights and bells	114
Wigwag and flashing lights	121
Wigwag, flashing lights, and bells	147
Watchman, 8 hours	119
Watchman, 16 hours	180
Watchman, 24 hours	228
Gates, 24 hours	241
Gates, automatic	333

Study of the coefficients listed above reveals several interesting comparisons. It will be noted that bells were approximately one and one-half times as effective in preventing accidents as the signs alone. It is likewise shown that wigwags were more effective than bells, and flashing lights were more effective than wigwags. It is also interesting to note that a combination of any two of these types of protection was more effective than either type alone, although in all cases the index for the combination was less than the sum of the individual indices.

A sufficient sample was not available to permit the calculation of a coefficient for gates operated less than 24 hours. The signs included both plain painted signs and those equipped with reflector buttons. No attempt was made to determine the effectiveness of one wigwag compared with two wigwags at a crossing, or to measure the protection of these types with signs as compared with the mechanical equipment without signs. While all of the figures are approximate and might be different for another sample of crossings, it is believed that the sample used was entirely sufficient and that the relations expressed between the various types of protection are logical and sufficiently accurate for use in the study which was made.

These coefficients are of particular value when circumstances indicate that the maximum of hazard reduction will result from improvement of the protective devices at a large number of crossings rather than from the same expenditure for the elimination of a few crossings.

Using the highway traffic, the train traffic, and the protection coefficient as independent variables and the number of accidents as the dependent variable, a correlation was made of the data using the following equation:

$$I=C\frac{H^{a}\times T^{b}}{P^{c}}+K\text{--------------}(2)$$

where

I = probable number of accidents in a 5-year period (this figure to be used as the hazard rating),
H = highway traffic—average daily number of vehicles,
T = train traffic—trains per day,
P = protection type coefficient,
C = constant,
K = additional parameter, and
a, b, and c = fractional exponents.

PROBABLE NUMBER OF ACCIDENTS IN 5 YEARS USED AS INDEX OF HAZARD

The probable number of accidents which would occur at a crossing in a 5-year period was assumed to be a sufficient index of the hazard at a crossing. From the correlation that was made it was found that the index could be calculated from the following equation:

$$I=1.28\frac{H^{0.170}\times T^{0.151}}{P^{0.171}}+K\text{----------}(3)$$

As an aid in calculating the hazard rating, curves were plotted showing the relationships between the hazard and the highway traffic (fig. 1), the train traffic (fig. 2), and the type of protection (fig. 3). From these data the hazard values for each contributing item considered may be determined, that is H^a, T^b, and P^c, and these inserted in equation 2. When these factors are inserted, the formula may be reduced to the following:

$$I=I_u+K\text{-----------------}(4)$$

where I = probable number of accidents in a 5-year period (the hazard rating),
I_u = an unbalanced rating, and
K = an additional parameter.

The factor K can be obtained from figure 4 which gives the variation of this factor for values of the unbalanced rating I_u. The product of H^a, T^b, and C divided by P^c, plus K, gives the probable number of accidents which will occur in a period of 5 years and a figure which is used in this study as the hazard rating.

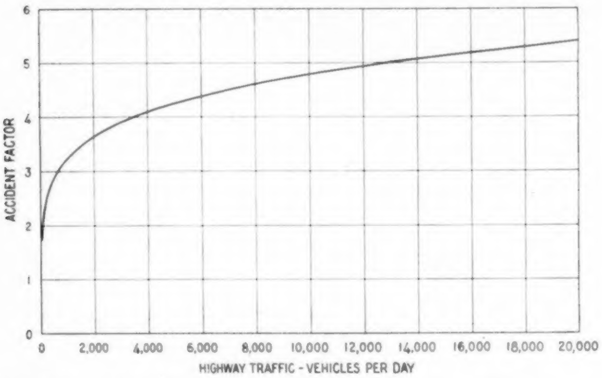

FIGURE 1.—RELATION BETWEEN HIGHWAY TRAFFIC AND ACCIDENTS, H^a.

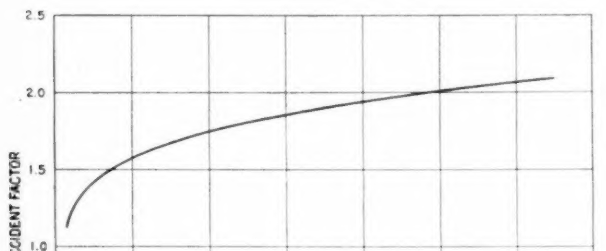

FIGURE 2.—RELATION BETWEEN RAILROAD TRAFFIC AND ACCIDENTS, T^b.

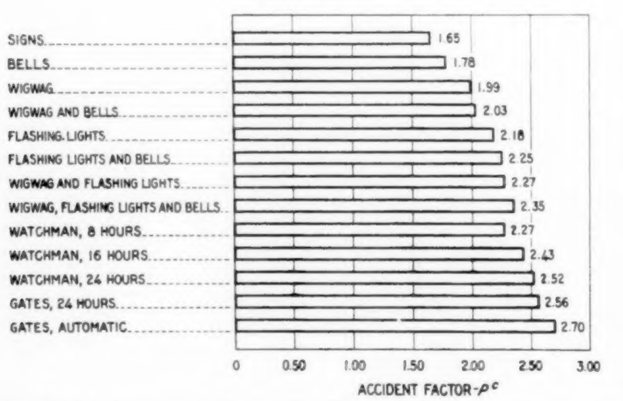

FIGURE 3.—ACCIDENT FACTORS, P^c, FOR VARIOUS TYPES OF PROTECTION.

Use of this formula is illustrated using data for two rural crossings in Oregon. The first crossing is in Clackamas County at milepost 13.27 on road 160. The average daily highway traffic is 3,442 vehicles; the average train traffic is 22 trains each day. The crossing is protected by wigwags. From figure 1, the hazard factor due to highway traffic of 3,442 vehicles per day is found to be 3.99. From figure 2 the factor due to train traffic of 22 trains per day is found to be 1.59; and from figure 3 the factor for a wigwag type of protection is found to be 1.99. Substituting these figures in equation 2, it is found that the hazard index

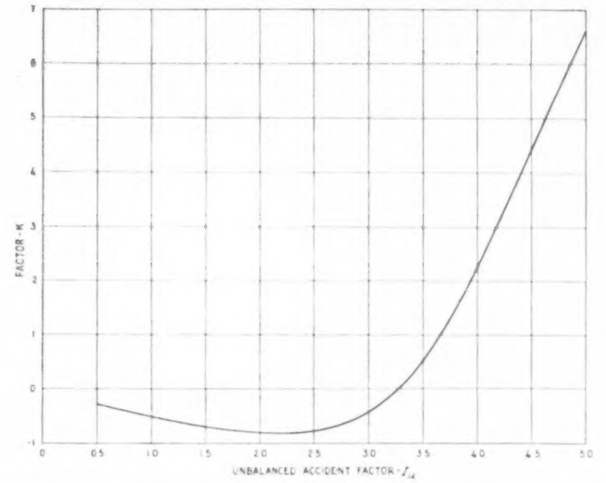

FIGURE 4.—RELATION BETWEEN UNBALANCED ACCIDENT FACTOR, COMPUTED FROM FORMULA $I_u=C\frac{H^a\times T^b}{P^c}$, AS COMPARED TO SMOOTHING FACTOR.

is equal to $1.28\frac{3.99\times 1.59}{1.99}+K$ or equal to $4.08+K$. From figure 4, K is determined to be $+2.58$ for a value of I_u of 4.08 and, with this figure for the parameter, the hazard index is 6.66.

The second crossing for which an index is calculated is in Yamhill County on route 32 at milepost 35.75. The average daily highway traffic at this crossing is 1,848 vehicles in a 24-hour day; the average train traffic is 4 trains each day. The protection consists of signs (approach signs and cross-bucks). Referring to figures 1, 2, and 3, the hazard factors due to highway traffic, train traffic, and to the signs as a type of protection are found to be 3.59, 1.20, and 1.65, respectively. When these figures are inserted in equation 2 it is found that I_u is 3.34 and, with this figure, K is determined to be $+0.06$ and the hazard index is 3.40.

To test the reliability of the formula, 123 crossings, the data concerning which were not used in the derivation of the formula, were rated by means of the formula. A large majority of these crossings were relatively safe, having had no more than three accidents recorded in the 5 years during which the accidents were reported. Some of them were at locations at which from six to eight accidents had occurred. The estimated number of accidents is compared with the actual number of accidents recorded at these 123 locations in table 1. The ranges of these figures are illustrated in figure 5.

TABLE 1.—*Average computed number of accidents using formula at 123 crossings in 10 States* [1] *compared to actual number of accidents recorded at those crossings*

Number of crossings	Actual number of accidents	Average computed accidents
15	1	1.21
47	2	1.84
39	3	3.05
11	4	3.69
3	5	5.20
5	6	6.18
1	7	7.36
2	8	8.37

[1] States included are as follows: Indiana, Iowa, Kentucky, Nevada, New Hampshire, Montana, Rhode Island, Utah, Wisconsin, and Wyoming.

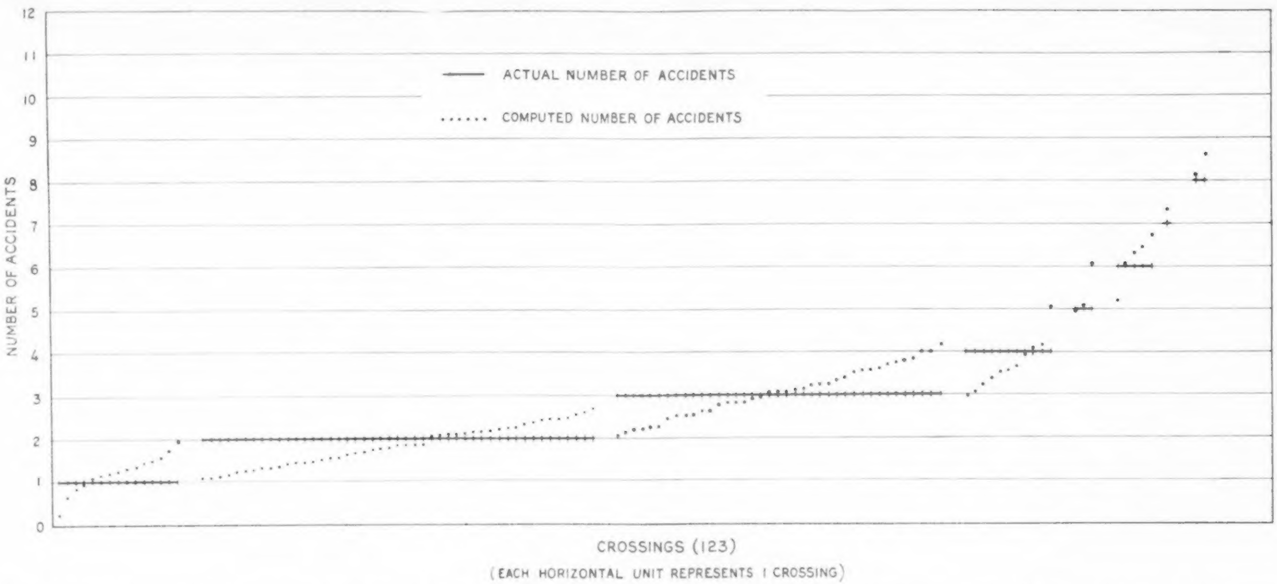

FIGURE 5.—COMPUTED NUMBER OF ACCIDENTS COMPARED TO ACTUAL NUMBER OF ACCIDENTS AT 123 CROSSINGS IN INDIANA, IOWA, KENTUCKY, NEVADA, NEW HAMPSHIRE, MONTANA, RHODE ISLAND, UTAH, WISCONSIN, AND WYOMING.

These data indicate that the computed number of accidents is generally in excess of the actual number of accidents at the low-accident crossings. These differences are not of great importance because priority information will ordinarily be of most value at a few of the most dangerous crossings. For instance, it is of little importance if a crossing which has had 1 accident is rated at 1.25, while one that has had 2 accidents is rated 2.19. In this case the latter is clearly more dangerous from a hazard standpoint. Neither is as dangerous as one rated 6.50. Although the sample of the high-accident crossings is small, a fairly consistent trend is noticeable.

The study of the various factors which might affect the hazard at a crossing indicated that several of these items exerted little influence on the calculation of the number of accidents at the locations and, therefore, were of little value in measuring the hazard. Although the effect of the physical factors was not sufficient to merit their inclusion in the hazard rating formula, these data should be considered in the assignment of priorities within groups of crossings of the same rating. The formula may be used to calculate the hazard rating of all the crossings, and then crossings with approximately the same hazard rating may be grouped and tabulated together with the physical factors (grade of approaches, angle of intersection, sight distance, etc.). Priorities within these groups may then be established on the basis of the relative hazard of physical factors. The relative importance of each physical factor, or combinations of these factors, must be determined.

ACCIDENT PROBABILITY AFFECTED BY OTHER FACTORS NOT CONSIDERED IN FORMULA

The probable number of accidents which will occur at any crossing cannot be obtained by means of this formula with a high degree of accuracy. While the factors used account for a large part of the variation in the accident probability, there are other variables that were not reported but probably have a definite influence. Probably there are also psychological factors that in many cases greatly affect the safety or danger of crossings but which cannot be measured numerically. The index rating, therefore, is no more than an indication of the variation of the number of accidents in conjunction with the variation of the factors considered and other items must be weighed before any set of crossings can be assigned rating numbers.

A portion of the probable error in the calculated accident record, or hazard index, may be due to the use of average daily figures for traffic. Inasmuch as large variations in these figures are apt to occur, it is probable that few of the accidents occurred at times when any of the conditions were as assumed by the measuring data. The peak highway traffic is generally found in the months of July and August, but the largest portion of the accidents occurs in November and December.

This variation between average daily traffic and the frequency of crossing accidents is illustrated in figure 6. From the two curves plotted on this figure it will be noted that the high points of traffic on the average section of highway are in July and August. The accident curve, however, indicates that in July and August the frequency of accidents is at a low point for the year and the high point is found to occur in November and December. Almost as many accidents occur in the night hours as during the day hours although the hourly traffic is less at night than during the day. The greatest frequency of accidents is usually found between 11 p. m. and midnight, when traffic is comparatively light. Likewise, train traffic may vary considerably from year to year, and train speed will vary from the average figures reported. Cases where the protection was changed during the 5-year period were omitted from consideration. It is believed that the protection coefficients are relatively constant for each type of protection listed. It is probable, however, that accident factors for highway traffic and train traffic would be changed somewhat if true values at the time of the accident could be obtained.

It is possible that traffic laws in the various States have some effect on the number of accidents which oc-

FIGURE 6.—VARIATION OF HIGHWAY TRAFFIC BY MONTHS IN 1939 AND VARIATION OF GRADE CROSSING ACCIDENTS BY MONTHS FROM 1933 TO 1937, INCLUSIVE.

cur at crossings on the highways of those States. The large variation in the grade-crossing accident record of the States must be due to causes other than chance; and, since States with high or low traffic volumes are found to have good and bad accident records indiscriminately, it appears that the traffic regulation may have some bearing on the variation in these figures. Data collected by the Interstate Commerce Commission for 1937 illustrate this. In their accident bulletin No. 106 it is shown that during 1937 the States of Rhode Island, Wyoming, Connecticut, Massachusetts, Maine, Nevada, New Jersey, New York, and New Hampshire had the best records while the States of Alabama, Illinois, Louisiana, Georgia, South Carolina, Mississippi, Kansas, Arkansas, and Indiana had the poorest records. The States having the poorer records had approximately 10 times the number of casualties per 10,000 vehicles registered as those more fortunate States whose accident records were better.

Another important fact to be considered is that the number of accidents that occur at any crossing in a 5-year period is comparatively small. Public opinion has forced most of the States to eliminate those crossings that were obviously the most undesirable or at which an excessive number of accidents occurred. Only one accident had occurred at most of the crossings for which the data were submitted, and for only a few of the crossings were five or more accidents reported.

Information could be gathered for a longer period of time and thus a greater number of accidents recorded but, if this were done, it is probable that traffic volumes and physical features at the crossing would have changed to such a degree that the data for the longer period would be little better from a statistical point of view.

MARYLAND CROSSINGS RATED ACCORDING TO RELATIVE HAZARD

Many of the highway planning survey organizations and others interested in this phase of highway planning have developed formulas for rating all grade crossings in which the coefficients are based on judgment. These formulas are approximate and probably do not give a complete and unbiased evaluation of the hazard. It is obviously impossible to assign numerical values to all situations and combinations of conditions with the assurance that these values are even approximately correct. However, when data are uniformly applied through one of these formulas, valuable relative information can be obtained. Several of the planning surveys have been able to collect more detailed information than was generally collected and have utilized this detailed knowledge in their evaluation formulas. The inclusion of the additional information has greatly aided in development of priority lists that coincided with the best public and engineering opinion.

Grade crossings in Maryland were independently rated by a committee of several individuals well acquainted with conditions throughout the State and competent to judge the relative hazards. These men were furnished with complete information with respect to all crossings in the State, this information consisting of tabulated data concerning the average daily highway traffic, the average daily railroad traffic, the physical characteristics of the crossing, and other pertinent information. The most dangerous crossings were put into five priority groups by State engineers, Federal engineers, and engineers of the railroads operating within the State. The ratings of crossings listed in table 2 represent the consensus of these men as to the relative hazard by groups. No attempt was made to arrange the crossings within any one priority group in order of their hazard.

The hazard formula has been applied to these 25 crossings and the results are also tabulated in table 2. From this table it will be noted that the sum of the hazard ratings calculated for the five crossings that were assigned first priority is greater than the total of the hazard ratings for any other group. Likewise, the sum of the hazard indices of the crossings in the second priority group is greater than the total hazard in those following this group. These totals decrease in a fairly uniform manner as follows:

Priority group:	*Total calculated hazard*
1	20.54
2	17.03
3	15.13
4	13.80
5	11.42

This indicates that the committee made a very good distribution of the crossings into the priority groups when judged by equation 4. While a rating on a hazard basis would change the priority rating of several crossings in the list, a study of the physical characteristics and local conditions, in combination with the hazard rating, might easily justify the priority groupings of these crossings.

A study of the priority ratings assigned by the committee of engineers, and the hazard ratings calculated by the formula, with respect to the individual crossings, indicated that insufficient credit was given by the committee to the effectiveness of gates and

(Continued on p. 142)

A STUDY OF BITUMINOUS CONCRETE PAVEMENTS IN OHIO

BY THE BUREAU OF TESTS OF THE OHIO DEPARTMENT OF HIGHWAYS, AND THE DIVISION OF TESTS, PUBLIC ROADS ADMINISTRATION [1]

During the 6 years prior to 1935, the Ohio Department of Highways carried on an extensive resurfacing program on the principal highways of the State using bituminous concrete over such old surfaces as portland cement concrete, brick, bituminous macadam, and surface-treated, water-bound macadam.

Evolving from a modified Topeka, containing mineral dust and requiring a seal coat, the resurfacing mixture used in most of the program was characterized by its small maximum size which facilitated laying and finishing with mechanical equipment and by the absence of any stone dust other than that naturally contained in the aggregates used. Seal coats were found to be unnecessary.

While these resurfacing mixtures proved to have excellent stability, good riding qualities, and generally good durability, they often developed considerable cracking. There were no definite failures but, in some cases, spalling occurred along the cracks and at the pavement edges and there were occasional instances of slight, though definite, surface raveling.

Following the construction season of 1936 and continuing through 1937, the Ohio Department of Highways and the Public Roads Administration collaborated in a program of sampling, testing, and study of selected areas representing all pavement conditions. Some modifications were made in the specifications and production methods for current work as the study progressed and these and further possible modifications are discussed.

The tests indicated that drastic changes in the asphalt, resulting from normal mixing operations, probably resulted in the loss of many months of satisfactory pavement service.

Alterations in the asphalt caused by mixing appeared to depend on the susceptibility of the asphalt to alteration and the conditions and time involved in the mixing operation.

The field is open for revisions in specifications to assure that the asphalt, as delivered, is resistant to alteration and that it is not unduly altered during mixing and placing.

THE Ohio Department of Highways began the development of its present specifications for hot-mixed, hot-laid asphaltic concrete surfacing in 1929. Starting with a modified Topeka mix employing lake sand and mineral filler and requiring a seal coat, the present specification, known as item T–50, hot-mixed, hot-laid asphaltic concrete, was developed permitting the use of local sand without the addition of mineral filler and dispensing with the seal coat. The specification was designed to provide mixtures of high density through the special grading of the aggregate rather than by the use of dust so that, when properly placed in the pavement, they would not only be dense and well sealed against surface moisture, but would also retain a nonskid surface texture. During recent years several hundred miles of this type of pavement have been constructed throughout the State.

In 1935, under the direction of the Ohio State Highway Testing Laboratory, a study was instituted to determine the factors affecting the durability of this type of surfacing. During the winter of that year samples were cut from 16 pavements that had been in service up to 5 years. The samples were selected from pavements ranging in condition from excellent to very poor. These samples were examined for density, crushing of aggregate, and condition of the recovered asphalt. A number of samples were also taken of freshly prepared mixtures and of pavements that had just been completed. The results of the tests on the recovered asphalt from these samples, as reported by T. W. Brannan,[2] indicated the need for a more intensive study of the problem.

In October 1936 arrangements were made to conduct a more detailed and comprehensive study of hot-mixed, hot-laid, asphaltic concrete pavements throughout the State in cooperation with the Public Roads Administration. A carefully planned investigation was outlined, and the taking and testing of additional samples was started immediately.

FACTORS AFFECTING SERVICE RECORD AND CURRENT CONDITION INVESTIGATED

The purpose of the cooperative investigation was to ascertain whether the service record and current condition of these asphaltic concrete pavements, which had been in service, could be correlated with such factors as changes in the consistency of the bitumen, degree of heterogeneity of the bitumen, or other factors that might be susceptible to satisfactory analysis.

Obviously, a great number of possible factors influenced the behavior of the pavements. Asphaltic materials from numerous sources and prepared by several processes of manufacture had been used. Construction procedure, drainage conditions, type and condition of base structure, age, and probably other factors had their effect. Consequently, a rather broad plan of study was necessary in order to obtain sufficient data to isolate the effects of the major variables. The procedure decided upon consisted of:

1. A general survey of the bituminous pavements of the State and selection of sections to be sampled.
2. Inspection and photographic recording of the general condition of the pavement surface near each selected sample location.
3. The taking of a large sample of the pavement surface course at each selected location.
4. Inspection and photographic recording of the type and condition of the base structure after removal of the sample.
5. Careful inspection of samples in the laboratory to note any peculiar appearance or condition.
6. Laboratory tests to determine the pavement density, the amount of asphalt contained in the mixture, and the specific gravity, grading, and compactibility of the extracted aggregate.

[1] The following employees of the Ohio Department of Highways participated in planning and directing this investigation: R. R. Litehiser, Chief Engineer of Tests T. W. Brannan, previously Assistant Engineer; J. H. Goshorn, Assistant Engineer, and T. F. Spencer, previously Assistant Engineer.
[2] Civil Engineering, vol. 7, No. 4, April 1937, page 291.

FIGURE 1.—A TYPICAL FIELD SAMPLE OF BITUMINOUS CONCRETE SURFACING.

7. Laboratory tests on the extracted asphalt recovered from solution by distillation.

In the tests made by the Public Roads laboratory, the asphalt was extracted by means of Rotarex extractors and, while in solution, was passed through a supercentrifuge to eliminate suspended dust. It was recovered from solution by Bussow's method as described in the Proceedings of the technical session of the Association of Asphalt Paving Technologists, January 23, 1936, page 160.

In the tests made by the State, the dust was removed by filtering through fuller's earth and the asphalt was then recovered by Abson's method as described in A. S. T. M. Proceedings, vol. 33, 1933, part II. Technical papers, page 704.

8. Comparison of the new test data with data obtained on the materials at the time of construction.

9. Roller stability tests on sawed specimens from a limited number of the samples.[3] These tests were made by the Public Roads laboratory only.

10. Analysis of the test data to evaluate the relative effect of various factors on the asphalt and on the behavior of the pavement. The data from the preliminary survey of 1935 were included in this analysis.

TESTS SHOW NEED FOR SOFTER ASPHALTS IN SURFACE COURSES

This report deals with test results on about 80 samples of Ohio T–50 asphaltic concrete containing 50–60 penetration petroleum asphalt. Forty-seven pavement sections are represented by these samples. About half of them were taken and tested in the preliminary study of 1935 and the rest during 1936 and 1937. All samples were tested by the State laboratory and 22 of the 1936–37 samples were divided and also tested in the Public Roads laboratory. Large samples were taken in order to provide adequate material for all tests required and any check tests that might be desired. A typical field sample is shown in figure 1.

In general, the paving mixtures were composed of from 45 to 55 percent of coarse aggregate, 30 to 48.5 percent of sand, and 6.5 to 10 percent of asphaltic cement. They were prepared at temperatures ranging between 275° and 375° F. The specifications for T–50 bituminous concrete surface-course mixtures, in effect at the time of this inspection and requiring the use of 50–60 penetration asphalt, are given in table 1 and the specified mixing and laying temperatures are shown in table 2. As a result of the information obtained through this investigation, softer asphalts (60–70, 70–80, and 85–100 penetration) are now being specified for asphaltic concrete surface courses.

[3] The test specimens were 4 inches wide, 8 inches long, and 2¼ inches deep. The procedure for making the roller stability tests is given in PUBLIC ROADS, vol. 16, No. 7, September 1935.

TABLE 1.—*Composition of T–50 wearing courses, types B and C, as required in present Ohio specifications*

Sieve sizes		T–50, Type B		T–50, Type C	
Passing sieve—	Retained on sieve—	Minimum	Maximum	Minimum	Maximum
		Percent	*Percent*	*Percent*	*Percent*
½-inch	⅜-inch	0	15		
⅜-inch	¼-inch	30	45	0	5
¼-inch	No. 4			20	40
No. 4	No. 6	0	8	0	30
No. 6	No. 8	0	10	0	10
No. 8	No. 16	5	20	5	20
No. 16	No. 50	10	30	8	30
No. 50	No. 100	1	18	1	15
No. 100	No. 200	1	5	1	5
No. 200		0	3	0	3
Bitumen[1]		6.5	8.5	7	10
Total retained on No. 6 sieve		45	55	45	55

[1] Asphalt of 50–60 penetration was specified until Mar. 1, 1939, when the requirement was changed to 50–70 penetration with the provision that the laboratory shall designate the grade (50–60 or 60–70) to be used on each project.

TABLE 2.—*Mixing and laying temperatures required in present Ohio specifications for T–50 surfacing*

Plant temperatures						Road or street temperatures		
Aggregate		Asphalt		Mixture		Minimum	Ideal	Maximum
Min.	Max.	Min.	Max.	Min.	Max.			
°F. 300	°F. 375	°F. 250	°F. 350	°F. 275	°F. 375	°F. 275	°F. 310–325	°F. 375

The data resulting from tests on the materials used in the pavements, the field inspection, and tests on the plant and pavement samples are given in tables 3 to 9 inclusive. The test data in tables 3, 4, 5, and 6 were obtained in the Ohio laboratory and those in tables 7, 8, and 9 in the Public Roads laboratory. In most cases, the test results on original asphalts reported by Ohio represent the individual cars of material that were used. When it was not possible to determine where particular cars of material had been used on the job, the average test values for the entire project are presented. Test results on recovered asphalts reported by Ohio are generally averages obtained by recovering and testing three separate samples of asphalt from each pavement sample. The test results reported by the Public Roads laboratory are not averages but represent individual tests.

In general, the results of the tests made on portions of individual pavement samples by the two laboratories were in good agreement. As was to be expected, there were a few instances of nonagreement because of nonuniformity of the samples or because of differences in the method of recovering the asphalt. These differences, however, caused no material disagreement in the conclusions reached by the two agencies. The conclusions in this report are therefore based on the work of both laboratories.

TABLE 3.—*Results of condition survey and data available at time of survey*

Sample No.	Project designation	County	Type of surfacing	Asphalt (tests made at time of construction)			Age of surfacing when sampled	Condition at time of sampling		
				Specific gravity	Penetration at 77° F.	Ductility at 77° F.		Base	Surface	Surface cracked more than base
						Cm.	*Months*			
1-A	2	Licking	T-50-A	1.015	52.9	97	67	Good	Very poor	Yes.
1-B	3	Ashtabula	T-50-B	1.018	53.0	100+	37			
1-B-1	3	do	T-50-B	1.018	53.0	100+	52	Good	Fair	Yes.
2-B	4	do	T-50-B	1.054	49.2	93	52			
2-B-1	4	do	T-50-B	1.054	49.2	93	66	Good	Very poor	Yes.
3-B	5	Greene	T-50-B	1.019	49.8	100+	62	Excellent	Good	No.
4-B	6	do	T-50-B	1.023	51.7	100+	61	do	do	No.
5-B	7	Clinton	T-50-B	1.005	54.0	100+	42	do	do	No.
6-B	8	do	T-50-B	1.016	53.0	100+	35	do	do	No.
8-B	9	Portage	T-50-B	1.043	55.8	100+	52	Very poor	Very poor	Yes.
9-B	10	Mahoning	T-50-B	1.019	52.4	100+	51	Fair	Poor	No.
10-B	11	Lake	T-50-B	1.022	54.2	100+	54	Good	Very poor	No.
11-B	12	Allen	T-50-B	1.034	54.1	100+	18	Excellent	Excellent	No.
12-B	13	Allen and Hardin	T-50-B	1.017	52.8	100+	53	Good	Poor	Yes.
12-B-1	13	do	T-50-B	1.017	52.8	100+	50	do	do	Yes.
13-B	14	Marion	T-50-B	1.005	53.8	100+	49	Excellent	Good	No.
14-B	15	Ashtabula	T-50-B	1.001	55.0	100+	8	do	Excellent	No.
15-B	16	do	T-50-B	1.004	52.5	100+	39	Good	Good	No.
16-B	17	do	T-50-B	1.000	56.8	100+	19	do	do	No.
17-B	18	do	T-50-B	1.013	53.0	100+	51	Very poor	Poor	Yes.
18-B	19	Clermont	T-50-B	1.004	53.2	100+	41	Good	Very poor	Yes.
19-B	20	Brown	T-50-B	1.002	53.4	100+	28	do	Good	No.
1-C	21	Harrison	T-50-C	.999	55.7	100+	0			
1-C-1	21	do	T-50-C	.999	55.7	100+	16	Good	Excellent	No.
2-C	22	Delaware	T-50-C	.997	54.4	100+	6			
2-C-1	22	do	T-50-C	.997	54.4	100+	20	Fair	Excellent	No.
3-C	23	Lucas	T-50-C	1.019	56.7	100+	18			
3-C-1	23	do	T-50-C	1.019	56.7	100+	32	Good	Good	No.
4-C	24	Harrison	T-50-C	1.015	55.8	100+	28			
4-C-1	24	do	T-50-C	1.015	55.8	100+	43	Very poor	Very poor	Yes.
5-C	25	Jefferson	T-50-C	1.016	54.0	100+	30			
5-C-1	25	do	T-50-C	1.016	54.0	100+	45	Good	Fair	No.
6-C	26	Tuscarawas	T-50-C	1.014	52.0	100+	30			
6-C-1	26	do	T-50-C	1.014	52.0	100+	46	Poor	Very poor	Yes.
7-C	27	Lake	T-50-C	1.015	54.3	100+	17			
7-C-1	27	do	T-50-C	1.015	54.3	100+	31	Good	Good	No.
8-C	28	Lorain	T-50-C	1.015	52.7	100+	26			
8-C-1 [1]	28	do	T-50-C	1.015	52.7	100+	40	Fair	Poor	No.
9-C	29	Richland	T-50-C	1.011	54.8	100+	29			
9-C-1	29	do	T-50-C	1.011	54.8	100+	42	Good	Good	No.
10-C	30	Ashtabula	T-50-C	1.019	55.7	100+	28			
10-C-1	30	do	T-50-C	1.019	55.7	100+	42	Poor	Poor	No.
11-C	31	Clinton	T-50-C	.998	56.0	100+	4			
11-C-1	31	do	T-50-C	.998	56.0	100+	18	Good	Excellent	No.
12-C	32	Morgan	T-50-C	.998	56.0	100+	5			
12-C-1	32	do	T-50-C	.998	56.0	100+	20	Fair	Excellent	No.
13-C	33	Muskingum	T-50-C	1.007	53.0	100+	18			
13-C-1	33	do	T-50-C	1.007	53.0	100+	32	Excellent	Excellent	No.
14-C	34	Franklin	T-50-C	1.009	56.0	100+	17			
14-C-1	34	do	T-50-C	1.009	56.0	100+	30	Good	Good	No.
15-C	35	Cuyahoga	T-50-C	1.017	54.2	100+	55	do	do	No.
16-C	36	Clermont	T-50-C	1.001	55.2	100+	15	Excellent	do	No.

[1] Data on this sample not included in table 5 and following analyses because results of individual tests by Ohio showed excessive variation.

The data resulting from the condition survey, together with such laboratory data on the materials used in the construction as were available before the survey was started, are presented in table 3. With one exception, all these samples, representing 35 paving projects, were taken from pavements that had been subjected to service.

The results of the condition survey, as given descriptively in the last three columns of table 3, represent the personal opinions of the observers as to the comparative condition of the surface and base on each section at the time of sampling and in the immediate vicinity of the area sampled. In selecting sections to be sampled an effort was made to find, wherever possible, areas in which damage to the surfacing could not be attributed in major part to failure of the base or subgrade; but in several cases it was found, when the base was uncovered by removal of the sample, that poor base conditions had contributed largely to damage sustained by the surface.

Pavements that are described as "very poor" were cracked extensively and the surfacing mixture showed spalling and raveling along the cracks and pavement edges, although none of the pavements showed complete failure. In some cases the surface was pot-holed to some extent but generally the riding quality was not seriously impaired. Straight longitudinal or transverse cracks that were obviously caused by joints in the base were not considered evidence of weakness in either the surface or the base. A general view of a pavement section typical of those classified as very poor is shown in figure 2–A. Figure 2–B is a close-up view of the same surface and shows in more detail the extensive irregular cracking and also the spalling and raveling.

Pavements that are described as "excellent" were, so far as could be detected by examination, in perfect condition. They showed no irregular cracking even on very close examination, and no raveling or edge spalling. Figure 3–A shows a general view of an excellent pavement with the patch replacing sample 11–C–1 in the right foreground. Figure 3–B is a detail view of the good water-bound macadam base on which the surface was constructed.

Ranging upward from very poor to excellent were the other three classifications—"poor," "fair" (or average), and "good." Naturally, these various intermedi-

TABLE 4.—*Results of Ohio laboratory tests on samples of freshly prepared mixtures and newly constructed surfacing containing negative-spot asphalt*

Field identification	Project No.	Source of sample[1]	Mixing temperature	Mixing time	Penetration of asphalt: Original	Penetration of asphalt: Recovered[2]	Penetration of asphalt: Portion retained	Asphalt producer No.	Mixing plant No.
			° F.	Minutes			Percent		
B-1	38	Truck	375	1	60	49	82	4	9
B-2	38	do	275	1	60	49	82	4	9
B-3	39	do	375	1	51	41	80	4	12
B-4	39	do	280	1	51	44	86	4	12
B-5	40	do	375	1	59	40	68	4	17
B-6	40	do	275	1	59	44	75	4	17
C-1	41	do	250	1	48	40	83	2	2
C-2	41	do	250	1	48	41	85	2	2
C-3	42	do	375	1	54	39	72	2	1
C-4	42	do	360	5	54	35	65	2	1
C-5	42	do	275	1	54	42	78	2	1
C-6	43	do	355	1	58	39	67	6	20
C-7	43	do	340	5	58	39	67	6	20
C-8	43	do	275	1	58	43	74	6	20
Average of truck samples							76		
1-X	44	Pavement		1	55	50	91	5	11
2-X	44	do		1	55	42	76	5	11
3-X	44	do		1	55	39	71	5	11
4-X	36	do		1	55	44	80	5	7
5-X	36	do		1	55	44	80	5	7
6-X	45	do		1	57	46	81	4	15
7-X	45	do		1	57	41	72	4	15
8-X	46	do		1	57	45	79	2	14
9-X	47	do		1	53	41	77	4	5
10-X	48	do		1	52	41	79	4	4
11-X	21	do		1	56	43	77	2-4	20
12-X	21	do		1	56	43	77	2-4	20
13-X	21	do		1	56	40	71	2-4	20
14-X	49	do		1	57	41	72	2	17
15-X	49	do		1	57	40	70	2	17
16-X	49	do		1	57	40	70	2	17
1-C	21	do		1	56	41	73	2-4	20
Average of pavement samples							76		

[1] All truck samples taken at the plant immediately after mixing.
[2] Asphalt recovered by Abson's method.

TABLE 5.—*Results of laboratory tests on field samples and correlation with field survey data*

Sample No.	Thickness surface and binder	Surface condition	Base condition	Voids data[1]: Voids in aggregate	Voids data[1]: Voids in pavement	Voids data[1]: Aggregate voids filled	Penetration of the asphalt 77° F. 100 g., 5 sec.: Original (before mixing)	Penetration: Recovered by Abson's method	Penetration: Portion retained	Ductility of asphalt 77° F., 5 cm., per min.: Original (before mixing)	Ductility: Recovered by Abson's method	Age of surface course	Oliensis spot test on recovered asphalt
	Inches			Percent	Percent	Percent			Percent	Cm.	Cm.	Months	
1-A	2.5	Very poor	Good	15.7	3.5	78	52.9	22.3	42	97	5.7	67	Negative.
1-B							53.0	32.5	61	100+		37	Do.
1-B-1	1.7	Fair	Good	14.5	.8	94	53.0	30.0	57	100+	9.6	52	Do.
2-B							49.2	10.0	20	93		52	Positive.
2-B-1	2.4	Very poor	Good	16.9	6.7	60	49.2	11.5	23	93	4.2	66	Do.
3-B	4.4	Good	Excellent	25.0	9.7	61	49.8	17.0	34	100+	4.0	62	Negative.
4-B	2.5	do	do	21.3	2.5	88	51.7	23.5	45	100+	11.5	61	Do.
5-B	2.0	do	do	18.9	2.4	87	54.0	28.0	52	100+	14.0	42	Do.
6-B	1.8	do	do	20.9	3.5	83	53.0	23.5	44	100+	5.3	35	Positive.
8-B	1.0	Very poor	Very poor	20.8	6.4	69	55.8	17.5	31	100+	4.3	52	Do.
9-B	2.8	Poor	Fair	16.3	1.7	90	52.4	28.7	55	100+	10.3	51	Negative.
10-B	2.8	Very poor	Good	18.1	4.5	75	54.2	23.0	42	100+	5.9	54	Do.
11-B	2.0	Excellent	Excellent	16.1	1.1	93	54.1	34.0	63	100+	34.0	18	Positive.
12-B	2.4	Poor	Good	17.1	1.7	90	52.8	22.5	43	100+	6.2	[2] 53	Do.
12-B-1	2.5	do	do	18.7	1.5	92	52.8	29.0	55	100+	13.0	[2] 50	Do.
13-B	2.0	Good	Excellent	17.5	1.5	91	53.8	31.5	59	100+	13.8	49	Negative.
14-B	2.6	Excellent	do	16.8	1.9	89	55.0	50.0	91	100+	100+	8	Do.
15-B	2.5	Good	Good	15.6	1.8	88	52.5	47.0	90	100+	100+	39	Do.
16-B	2.0	do	do	15.0	.4	97	56.8	52.0	92	100+	100+	19	Do.
17-B	1.5	Poor	Very poor	16.7	2.1	87	53.0	36.5	69	100+	28.7	51	Do.
18-B	1.1	Very poor	Good	21.4	4.9	77	53.2	19.5	37	100+	4.9	41	Do.
19-B	2.3	Good	do	23.9	6.6	72	53.4	26.0	49	100+	21.4	28	Do.
1-C							55.7	41.0	74			0	Do.
1-C-1	1.1	Excellent	Good	23.3	5.6	76	55.7	32.0	57	100+	37.1	16	Do.
2-C							54.4	48.0	88			6	Do.
2-C-1	2.2	Excellent	Fair	16.6	0	100	54.4	54.0	99	100+	100+	20	Do.
3-C							56.7	27.0	48			18	Positive.
3-C-1	3.3	Good	Good	20.3	2.1	90	56.7	21.5	38	100+	6.0	32	Do.
4-C							55.8	19.0	34			28	Do.
4-C-1	1.7	Very poor	Very poor	21.0	5.9	72	55.8	22.0	39	100+	4.8	43	Do.
5-C							54.0	30.0	56			30	Do.
5-C-1	3.0	Fair	Good	19.8	6.7	66	54.0	23.0	43	100+	6.5	45	Do.
6-C							52.0	24.0	46			30	Do.
6-C-1	2.2	Very poor	Poor	18.0	2.5	86	52.0	21.5	41	100+	6.0	46	Do.
7-C							54.3	29.0	53			17	Do.
7-C-1	2.0	Good	Good	15.5	.8	95	54.3	32.0	59	100+	7.9	31	Slightly positive.
8-C							52.7	39.5	75			26	Positive.
9-C							54.8	29.5	54			29	Negative.
9-C-1	1.4	Good	Good	18.8	2.7	86	54.8	21.5	39	100+	5.6	42	Slightly positive.
10-C							55.7	29.0	52			28	Positive.

[1] The voids were computed from densities determined by immersion in water. The densities were determined on the combined top and binder courses.
[2] Difference in age accounted for by time interval between laying first and last parts of section.

TABLE 5.—*Results of laboratory tests on field samples and correlation with field survey data*—Continued

Sample No.	Thickness surface and binder	Surface condition	Base condition	Voids data[1]: Voids in aggregate	Voids data[1]: Voids in pavement	Voids data[1]: Aggregate voids filled	Penetration of the asphalt 77° F. 100 g., 5 sec.: Original (before mixing)	Penetration: Recovered by Abson's method	Penetration: Portion retained	Ductility of asphalt 77° F., 5 cm., per min.: Original (before mixing)	Ductility: Recovered by Abson's method	Age of surface course	Oliensis spot test on recovered asphalt
	Inches			*Percent*	*Percent*	*Percent*			*Percent*	*Cm.*	*Cm.*	*Months*	
10-C-1	2.2	Poor	Poor	16.7	1.3	92	55.7	32.0	57	100+	11.1	42	Negative.
11-C							56.0	38.0	68			4	Do.
11-C-1	3.0	Excellent	Good	19.9	5.9	70	56.0	35.0	63	100+	36.0	18	Do.
12-C							56.0	48.5	87			5	Do.
12-C-1	2.8	Excellent	Fair	15.0	1.2	92	56.0	43.0	77	100+	58.0	20	Do.
13-C							53.0	42.0	79			18	Do.
13-C-1	2.4	Excellent	Excellent	15.8	.5	97	53.0	45.0	85	100+	100+	32	Do.
14-C							56.0	43.0	77			17	Do.
14-C-1	1.6	Good	Good	17.6	0	100	56.0	41.0	73	100+	23.0	30	Do.
15-C	1.6	do	do	16.9	3.4	80	54.2	20.5	38	100+	4.9	55	Positive.
16-C	2.7	do	Excellent	21.3	5.4	75	55.2	31.0	56	100+	62.0	15	Negative.

TABLE 6.—*Summary of data on condition of pavement as related to hardening of the asphalt* [1]

Condition of surface	Number of samples	Penetration of asphalt recovered by Abson's method: Minimum	Penetration: Maximum	Penetration: Average	Portion of original penetration retained: Minimum	Portion retained: Maximum	Portion retained: Average
NEGATIVE-SPOT ASPHALTS							
					Percent	*Percent*	*Percent*
Very poor	3	19.5	23.0	21.6	37	42	40
Poor	1	28.7	28.7	28.7	55	55	55
Fair	1	30.0	30.0	30.0	57	57	57
Good	9	17.0	52.0	33.0	34	92	61
Excellent	6	32.0	54.0	43.2	57	99	79
POSITIVE-SPOT ASPHALTS							
Very poor	1	11.5	11.5	11.5	23	23	23
Poor	2	22.5	29.0	25.8	43	55	49
Fair	1	23.0	23.0	23.0	43	43	43
Good	5	20.5	32.0	23.8	38	59	44
Excellent	1	34.0	34.0	34.0	63	63	63
ALL ASPHALTS							
Very poor	4	11.5	23.0	19.1	23	42	36
Poor	3	22.5	29.0	26.7	43	55	51
Fair	2	23.0	30.0	26.5	43	57	50
Good	14	17.0	52.0	29.7	34	92	55
Excellent	7	32.0	54.0	42.0	57	99	76

[1] No test results included for samples taken where the base was in poor or very poor condition.

ate classifications could not be made with mathematical precision, but in most cases the classification used represented the judgment of at least two observers. None of the pavements examined showed any evidence of lack of stability of the surfacing mixture such as would have been indicated by shoving, corrugations, or rutting.

MIXING OPERATIONS CAUSED DETRIMENTAL CHANGES IN ASPHALT

Classification of the bases was made by observing the amount of cracking and vertical misalinement revealed by removal of the surfacing sample and the soil and drainage conditions as evidenced by the presence or absence of excessive moisture or mud in the base. The slope and character of the land along the right-of-way and the presence or absence of adequate surface drainage features were also taken into account. The appearance of some typical bases exposed by removal of the surfacing samples is shown in figure 4.

FIGURE 2.—A, GENERAL VIEW, AND B, SURFACE DETAIL OF A PAVEMENT THAT WAS RATED VERY POOR. NOTE THE SPALLING ALONG THE CRACKS AND THE RAVELED CONDITION OVER A LARGE PORTION OF THE PAVEMENT. SAMPLE 8-B WAS TAKEN AT THIS LOCATION. THE PATCHED SAMPLE HOLE CAN BE SEEN IN THE RIGHT CENTER OF THE UPPER PICTURE.

No record was made of the condition of the pavements represented by the samples taken during the preliminary study in 1935 by the State alone. These are the samples numbered 1-B and 2-B and 1-C to 14-C, inclusive. However, when these sections of pavement were again sampled in 1936 as a part of the enlarged study program, their condition was noted. These later samples are numbered 1-B-1, 1-C-1, etc., the notation (-1) being added to distinguish them from the earlier ones. They were not necessarily taken in the same areas of the various projects as those of the first series, and for this reason direct comparisons be-

TABLE 7.—*Correlation of pavement performance with the results of tests on surfacing samples by the Public Roads Administration laboratory*

SATISFACTORY PAVEMENTS

Sample No.	Age of surface	Condition of base	Characteristics associated with satisfactory performance				Characteristics associated with unsatisfactory performance				Condition of surface
			Roller stability less than 100	Asphalt recovered by Bussow's method			Roller stability more than 100	Asphalt recovered by Bussow's method			
				Penetration retained more than 55 percent	Ductility retained more than 10	Spot test negative		Penetration retained not more than 55 percent	Ductility retained less than 10	Spot test positive (xylene equivalent)	
	Months			*Percent*				*Percent*			
11-B	18	Excellent	47	57	32					24-28	Excellent.
11-C-1	18	Good		63	36	Yes					Do.
12-C-1	20	Fair	44	71	55	Yes					Do.
13-C-1	32	Excellent	16								Do.
3-B	62	do				Yes		48	5		Good.
4-B	61	do		56	13	Yes					Do.
5-B	42	do		63	23	Yes					Do.
6-B	35	do									Do.
13-B	49	do	84	63	14	Yes					Do.
15-B	39	Good	44								Do.
19-B	28	do	89	60	52	Yes					Do.
14-C-1	30	do	12	79	21					4-8	Do.
15-C	55	do	51					39	4	16-20	Do.

UNSATISFACTORY PAVEMENTS

Sample No.	Age of surface	Condition of base	Roller stability less than 100	Penetration retained more than 55 percent	Ductility retained more than 10	Spot test negative	Roller stability more than 100	Penetration retained not more than 55 percent	Ductility retained less than 10	Spot test positive (xylene equivalent)	Condition of surface
12-B	53	Good									Poor.
12-B-1	50	do	4					45	6	24-28	Do.
8-C-1	40	Fair						55	8	20-24	Do.
1-A	67	Good					17				Very poor.
2-B-1	66	do					478	28	4	12-16	Do.
8-B	52	Very poor					109	36	4	4-8	Do.
18-B	41	Good				Yes	290	47	6		Do.
4-C-1	43	Very poor						39	5	12-16	Do.
6-C-1	46	Poor					225	48	7	16-20	Do.

FIGURE 3.—A, GENERAL VIEW OF AN EXCELLENT PAVEMENT, AND B, DETAIL OF THE GOOD WATER-BOUND MACADAM BASE EXPOSED BY REMOVAL OF THE SAMPLE. THE DARK SPOT IN THE RIGHT FOREGROUND IN A IS THE PATCH THAT WAS PLACED AFTER THE REMOVAL OF SAMPLE 11-C-1.

tween the earlier and later samples from individual projects were not particularly satisfactory.

The field and laboratory data pertaining to the 31 samples obtained either at the plant or from the freshly laid pavement on 14 projects during construction in 1935, are given in table 4 and the results of laboratory tests on the samples from the pavements in service (those of table 3) are shown in table 5.

As shown in table 4, the amount of hardening or loss of penetration caused by the mixing operation alone was generally quite extensive, averaging 24 percent and ranging from 14 to 35 percent for the 14 samples of freshly prepared surfacing mixture tested. The average penetration loss for the 17 samples of newly laid pavement was exactly the same as for the 14 samples of freshly prepared mixture, namely, 24 percent, while the minimum and maximum losses were 9 and 30 percent, respectively. While these data cannot be said to furnish conclusive proof that no hardening occurs during handling and laying operations because the mixtures sampled at the plant were not the same as those sampled from the newly laid pavement, these as well as data obtained in other investigations by the Public Roads Administration do indicate that such hardening is relatively unimportant as compared to that sustained during the mixing operation.

TABLE 8.—*Comparison of the characteristics of the extracted bitumens from top and binder courses* [1]

Sample No.	Hardening (loss of penetration)					Decrease in ductility		Oliensis spot test on recovered asphalt, xylene equivalent	
	Original penetration of asphalt, top and binder	Penetration of recovered asphalt		Decrease in penetration [2]					
		Top	Binder	Top	Binder	Top	Binder	Top	Binder
				Percent	*Percent*	*Percent*	*Percent*		
4-B	52	29	32	44	38	87+	80+	0	0
15-C	54	21	26	61	52	96+	94+	16-20	16-20
12-B-1	53	24	33	55	38	94+	91+	24-28	40-44
8-C-1	53	29	31	45	42	92+	92+	20-24	20-24

[1] Asphalt recovered by Bussow's method.
[2] 100 minus percentage of original penetration retained.

TABLE 9.—*Relation of pavement and aggregate density to grading of the aggregate*

Sample No.	Results of tests of surfacing samples		Compaction tests on extracted aggregate		Mechanical analysis of extracted aggregate (total aggregate passing)				
	Density (grams per cc.)	Computed aggregate density [1]	Aggregate density [2] (vibrated)	Aggregate voids overfilled [3]	¾-inch sieve	⅜-inch sieve	No. 4 sieve	No. 8 sieve	No. 200 sieve
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1-A	2.361				100	84.7	60.6	45.1	3.0
2-B-1	2.237	81	88	0	95	85.0	48.9	35.9	3.6
3-B	2.256	77	83	.8	100	93.0	64.2	47.0	4.5
4-B	2.316	78	81	0	100	93.0	70.7	60.0	6.0
5-B	2.343	79	85	2.7	100	93.0	62.3	54.0	6.3
6-B	2.290	77	82	.7	100	93.0	65.6	55.0	6.6
8-B			89	3.0	100	90.6	48.4	38.2	4.7
11-B	2.375	82	89	2.8	100	84.1	49.2	40.5	4.2
12-B	2.356	81	86	2.2	100	96.3	60.0	50.4	3.4
12-B-1	2.360	80	90	4.5	100	95.6	61.0	45.8	4.8
13-B	2.340	81	88	2.9	100	96.1	64.5	53.1	6.7
15-B	2.385	84	88	2.3	100	97.3	60.7	42.0	3.2
18-B	2.103	77	82	0	100	86.9	63.6	51.9	3.8
19-B	2.051	74	86	3.0	100	77.3	[illegible]2.2	43.8	4.1
4-C-1	2.175	77	87	2.6	100	97.7	69.4	44.8	4.7
6-C-1	2.247	79	87	2.5	100	93.4	78.2	45.6	3.0
8-C-1	2.229					100.0	65.1	42.2	2.5
11-C-1	2.115	76	81	[4] −1.2	100	82.2	57.0	46.8	4.1
12-C-1	2.359	82	86	1.3		100.0	84.0	50.1	4.7
13-C-1	2.278	81	87	2.7	100	97.0	70.2	44.5	3.8
14-C-1			90	4.6		100.0	74.0	40.0	7.2
15-C	2.282	81	87	1.2	100	97.6	60.2	37.9	3.3

[1] Percentage of aggregate volume per unit of total volume in the sample of field-compacted surfacing.
[2] Percentage of aggregate volume per unit of total volume in the sample of extracted aggregate compacted by vibration.
[3] Difference between actual asphalt content of the field sample and the asphalt capacity of the extracted aggregate compacted by vibration. (Percentages based on dry weight of aggregate.)
[4] As indicated by the minus sign, this mixture was underfilled.

The ductility of the asphalt before and after mixing was 100+ for all 14 of the freshly prepared surfacing mixtures. Initial ductilities for the asphalts contained in the 17 samples of newly laid pavement were also 100+ but the ductility test was made on the recovered asphalt for only 3 of the 17 samples. Two of these had a ductility of 100+ and the other, 90.

None of these data are included in table 4 because they fail to give a true picture of the effect of mixing on the ductility. Certainly, they cannot be considered to show that no change occurred in ductility because the machine available for making the test, being only 100 centimeters long, was not capable of measuring the full ductility either of the original materials or any but one of the recovered asphalts on which the test was made. Tests with the 250-centimeter ductility machine of the Public Roads laboratory have shown that ductilities of 200 centimeters are not uncommon for 50–60 asphalts and some samples have been found to have ductilities of 250+. Thus the initial ductilities reported by the laboratory but omitted from table 4 and most of those reported in table 5 for the pavements in service fail to represent the true ductilities.

Some data are given in table 4 on the effect of variations in mixing temperature and mixing time on the hardening of the asphalt. Although limited in number, the tests show quite definitely that 375° F., the highest mixing temperature permitted under the T–50 specification, is considerably more detrimental to the asphalt than the minimum specified temperature of 275° F. The comparisons were made at six different mixing plants as shown in the right-hand column of table 4.

At plant No. 9 no difference was found in the amount of hardening caused by mixing temperatures of 375° F. and 275° F. At plant No. 12 the percentage of the original penetration retained after 1 minute of mixing at 375° F. was 80 and at 280° F. it was 86, the difference in percentage being 6 for a temperature difference of 95° F. or 6.3 when estimated for a temperature difference of 100° F. The estimated or actual difference for the other plants on the basis of a temperature difference of 100° F. was 7 for plant No. 17, 6 for plant No. 1, and 10 for plant No. 20. The average difference for these five plants where the temperature was varied was 5.9.

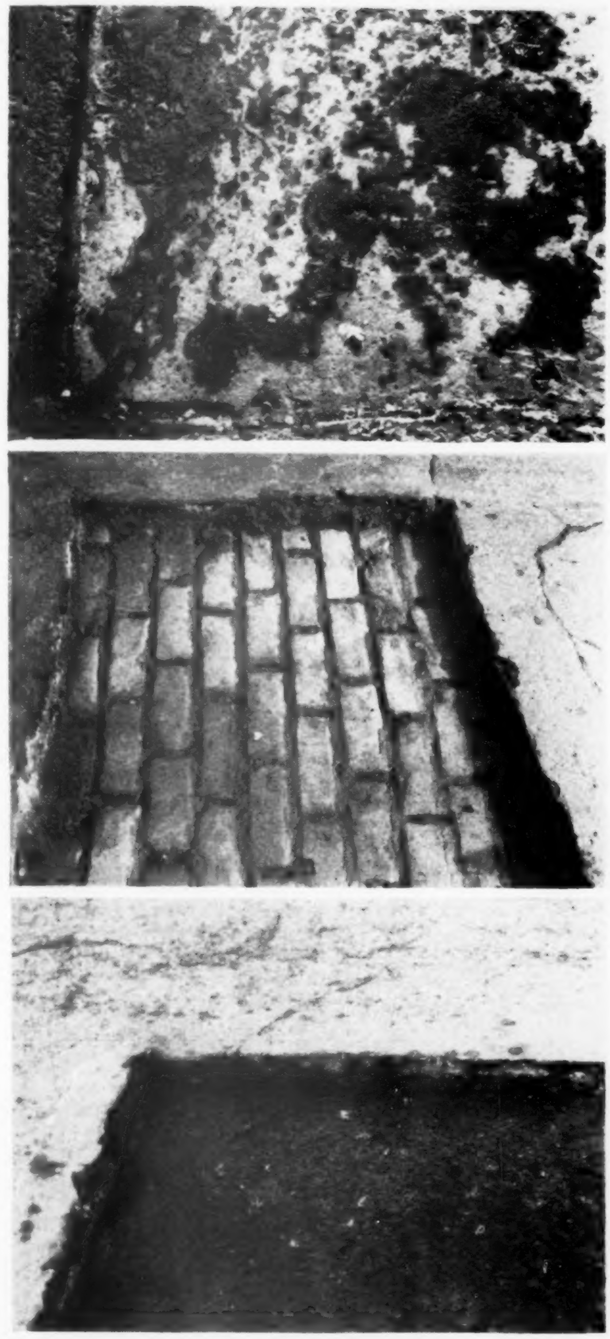

FIGURE 4.—TYPICAL BASES EXPOSED BY REMOVAL OF SAMPLES. A, CONCRETE BASE SHOWING SHATTERING AND SCALING (EXTREME LEFT OF PICTURE); B, BRICK BASE WHICH SHOWED SOME MOVEMENTS AS EVIDENCED BY THE CRACK IN THE GROUT FILLER (EXTREME RIGHT OF PICTURE); C, SURFACE-TREATED, WATER-BOUND MACADAM BASE IN GOOD CONDITION.

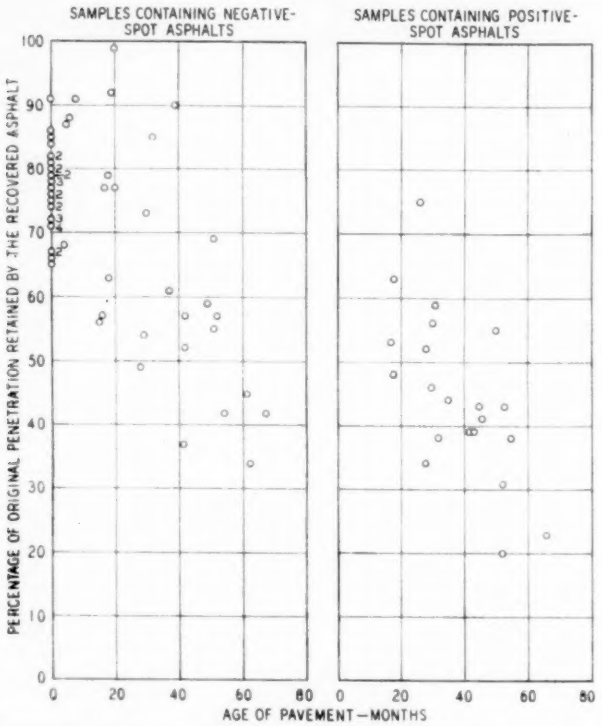

FIGURE 5.—RELATION OF PERCENTAGE OF ORIGINAL PENETRATION RETAINED BY THE RECOVERED ASPHALT TO THE AGE OF THE PAVEMENT. (POINTS SHOWN ON ZERO AGE LINE FOR NEGATIVE-SPOT GROUP REPRESENT 31 SAMPLES OF FRESHLY PREPARED OR NEWLY LAID PAVING MIXTURE; NUMERALS BESIDE SOME OF THESE POINTS INDICATE THAT 2, 3, OR 4 SAMPLES ARE REPRESENTED BY THESE POINTS.)

In other words, the loss in penetration was indicated to be about 6 percent greater for a mixing temperature of 375° F. than for a temperature of 275° F.

Comparison of sample C–3 with sample C–4 and sample C–6 with sample C–7, table 4, shows the effect of varying the mixing time with the temperature maintained approximately constant. On the basis of the temperatures actually maintained, lengthening the mixing time to 5 minutes as compared to the normal 1 minute, increased the amount of hardening by a percentage difference of 7 in one case and did not appear to affect the amount of hardening in the other.

AGING IN PAVEMENT APPARENTLY CAUSED DETRIMENTAL CHANGES IN THE ASPHALT

The results of tests on the asphalts recovered from pavements in service, table 5, indicate that important changes continued to develop after the paving mixtures were laid and placed in service.

The effect of aging in service on the penetration of the asphalt is shown graphically in figure 5. This effect appears to differ somewhat for the negative-spot and the positive-spot asphalts and is, therefore, shown separately for the two respective groups of samples in the left and right portions of the figure. For both classes of material, a definite tendency is shown for penetration to fall off as the age of the pavement increases but the wide range of values of retained penetration for any particular age makes it impractical to present curves to show mean rates of hardening or to attempt to predict for any given set of materials and conditions what rate of hardening should be expected.

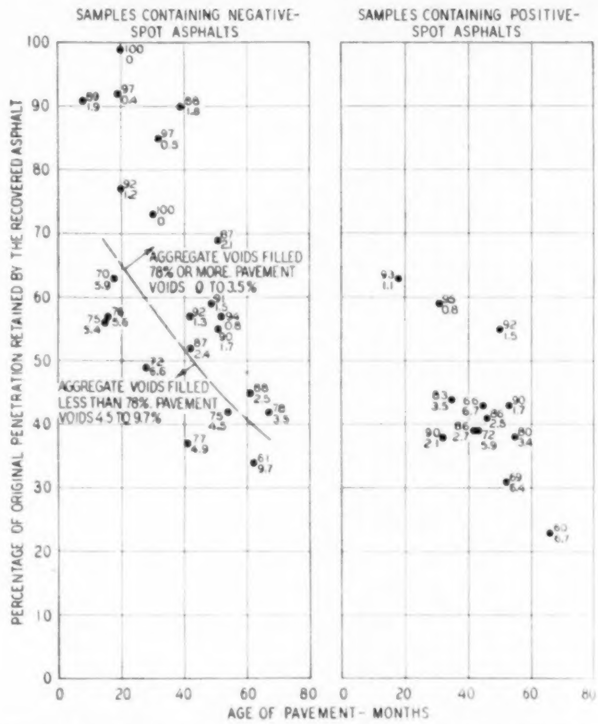

FIGURE 6.—EFFECT OF VOID CONTENT AND PERCENTAGE OF AGGREGATE VOIDS FILLED WITH ASPHALT ON HARDENING OF THE ASPHALT WITH AGE. (UPPER NUMBER BESIDE EACH POINT REPRESENTS PERCENTAGE OF AGGREGATE VOIDS FILLED WITH ASPHALT; LOWER NUMBER REPRESENTS PERCENTAGE OF AIR-FILLED VOIDS IN PAVEMENT SAMPLE.)

It is believed, however, that the data are sufficiently indicative when considered in relation to the losses at the mixing plant to show (1) that the very serious losses that occur at the plant injure the asphalt as much as would several years of service, and (2) that reasonable measures that might tend to reduce penetration losses, both at the plant and in the pavement, should be investigated.

The wide dispersion of the points in both parts of figure 5 from any conceivable mean rate of hardening indicate that there may be several factors capable of greatly modifying the effect of age on the amount of hardening shown by the asphalt in the pavement.

One of these factors is the susceptibility of the asphalt itself to weathering and this susceptibility doubtless varies with the source of the crude oil, the method of manufacture, and perhaps other considerations. The fact that, as a group, the recovered asphalts that reacted negatively to the spot test differed materially in the amount of hardening shown at a given age from those that gave positive spots (see fig. 5) is indicative of this.

A second factor that appears from the data to have a marked effect on the rate of hardening and to account, therefore, for a considerable part of the dispersion of points, particularly those representing negative-spot asphalts, is the denseness of the finished pavement as reflected in the percentage of the aggregate voids in the compacted pavement filled with asphalt and the corresponding percentage of air-filled or pavement voids.

The relation of this factor of pavement density to the amount of hardening of the asphalt in the pavement is shown in figure 6. This figure is a repetition of figure 5 with all samples of zero age and all samples for which

density figures were lacking omitted. The percentages of aggregate voids filled with asphalt are shown as whole numbers beside the individual points and the percentages of pavement voids, these being less than 10 in all cases, are also shown.

In the case of the samples containing negative-spot asphalt, it happened that most of those showing extremely high or extremely low retained penetration were taken after 1935. Hence, the test data included their densities. The ones having 78 to 100 percent of their aggregate voids filled with asphalt and having corresponding pavement voids of 3.5 to 0 percent contained asphalts that, at equal ages, had retained higher percentages of their original penetration than those having less than 78 percent of their aggregate voids filled and having corresponding pavement voids of 4.5 to 9.7 percent. This suggests that about 4 percent may be a critical void content from the standpoint of weathering for this type of mixture.

Thorough filling of the aggregate voids may be accomplished, without undue compaction effort but at the possible expense of skid resistance, by the use of extremely rich mixtures. It may also be accomplished on relatively leaner mixtures by the expenditure of greater compaction effort but at the expense, in extreme cases, of detrimental crushing of the aggregate. Within reasonable limits, either means may be selected as the primary design consideration depending upon the purpose for which the mixture is intended and whether high stability or great flexibility is desired.

Several of the samples containing positive-spot asphalt and showing extreme variations in loss of penetration (see fig. 5) were among the group taken in 1935 for which density figures are not available. The relation between pavement voids and loss of penetration through aging, shown by the remaining 13 samples of known density (see fig. 6) is neither as marked nor as consistent as was the case for the negative-spot samples. However, there is some indication that the hardening shown by the positive-spot asphalts was also affected by the void contents of the pavements.

While the data on the plant samples and those from the newly laid pavement failed, as previously noted, to give any indication of ductility losses incident to mixing because of the lack of information concerning the true initial or final ductilities involved, the samples from the pavements in service furnished at least partially satisfactory information on the loss of ductility with aging. Again, as in the case of the plant samples, the true initial ductilities are not known but even with the reported initial ductilities as a starting point, these being 100+ in all but three cases (see table 5), the loss of ductility during service in the pavement was generally very extensive and furnished further evidence of the very definite and presumably detrimental changes that were induced in the asphalt by the conditions of service.

The relation of retained ductility to pavement age is shown in figure 7. The data for the samples containing negative-spot asphalts are plotted in the left panel while the data for the positive-spot samples are at the right. Although, as in the case of penetrations (fig. 5) it is impractical to attempt to draw curves to show the average rate of ductility loss, it is quite apparent that there is a general trend for ductility to decrease rather rapidly with increasing age. It is also apparent that as a group and for comparable ages, the positive-spot

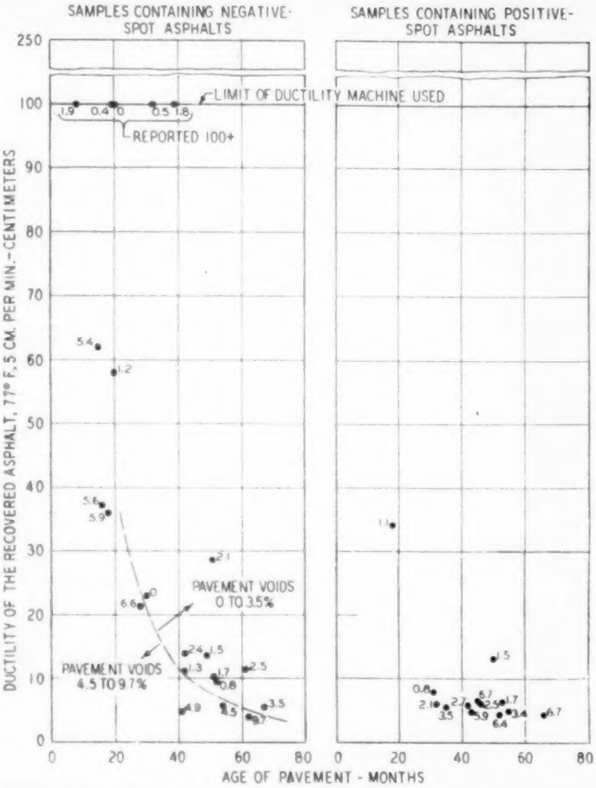

FIGURE 7.—RELATION OF PAVEMENT AGE AND PAVEMENT VOIDS TO DUCTILITY OF THE RECOVERED ASPHALT. (FIGURES BESIDE INDIVIDUAL POINTS REPRESENT PERCENTAGES OF VOIDS IN THE PAVEMENT SAMPLES.)

asphalts retained somewhat lower residual ductilities than the negative-spot materials.

The void contents of the pavement samples are again shown beside the individual points as in figure 6. Here, as in figure 6, where loss of penetration was considered, it is apparent that the void content of the pavement had a consistent and fairly important effect on the amount of alteration or weathering shown by the negative-spot asphalts. Those from samples having void contents of 3.5 percent or less showed consistently higher residual ductilities than those from pavements of comparable age having void contents of 4.5 percent or more. From the data available, however, the ductilities of the positive-spot asphalts appear to have been little affected by the void contents of the pavements (see fig. 7).

TEST RESULTS CORRELATED WITH SERVICE BEHAVIOR

So far, the discussion has been confined primarily to the changes that took place in the asphalt as a result of the mixing process and subsequent exposure and an effort has been made to show how various factors affected these changes.

In the following graphs and discussion, the various factors for which data have been presented, will be considered with respect to the condition of the pavement at the time of sampling.

Figure 8 shows the relation of surface condition to base condition. There is, as would be expected, a general tendency for good base conditions to be reflected in good surface conditions. All of the fair (average) and good surfaces and all but two of the excellent surfaces were found on bases that were in good or excellent

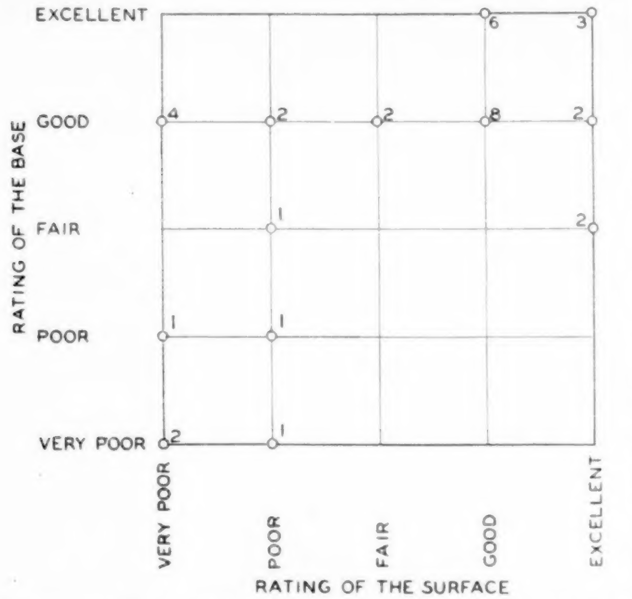

FIGURE 8.—RELATION OF SURFACE CONDITION TO BASE CONDITION. (NUMERALS INDICATE NUMBER OF SECTIONS.)

condition. The other two excellent surfaces were on fair (average) bases. However, the fact that very poor and poor surfaces were found on several good bases indicates that other factors than base condition must be taken into consideration to account for all surface conditions. In order that unsatisfactory surface conditions that are properly attributable to base conditions may not be charged improperly against the quality of the surfacing mixtures or their constituent materials, the data to be used in the following analyses and graphs in the study of these other factors will be only those obtained from samples taken where the base was rated average or better.

Figures 9 and 10, which were plotted from data in table 5, show the relation of surface condition to the amount of hardening developed in the asphalt. In figure 9, the comparison is made on the basis of the actual penetrations as determined on the samples of recovered asphalt, while in figure 10 these residual penetrations have been converted to percentages of the original penetrations as determined at the time of construction. The relations of figures 9 and 10 are also shown in table 6 which is a summary of the hardening data in table 5.

From the relations shown in table 6 and figures 9 and 10, the effect of hardening on the behavior of the pavement is clearly apparent. For the asphalts in very poor pavements, the retained penetration was in no case more than 42 percent of the original. In the poor and fair (average) pavements, the maximum retained penetrations were respectively 55 percent and 57 percent.

In contrast to the pavements classified as average or poor, the asphalts in the excellent pavements had retained from 57 to 99 percent of their original penetration.

Of the asphalts from good pavements, five had retained more than 57 percent and nine had retained less than 57 percent of their original penetration.

The foregoing analysis, which is confined entirely to cases where the bases were average or better, indicates that asphaltic concrete surfaces of the type studied can

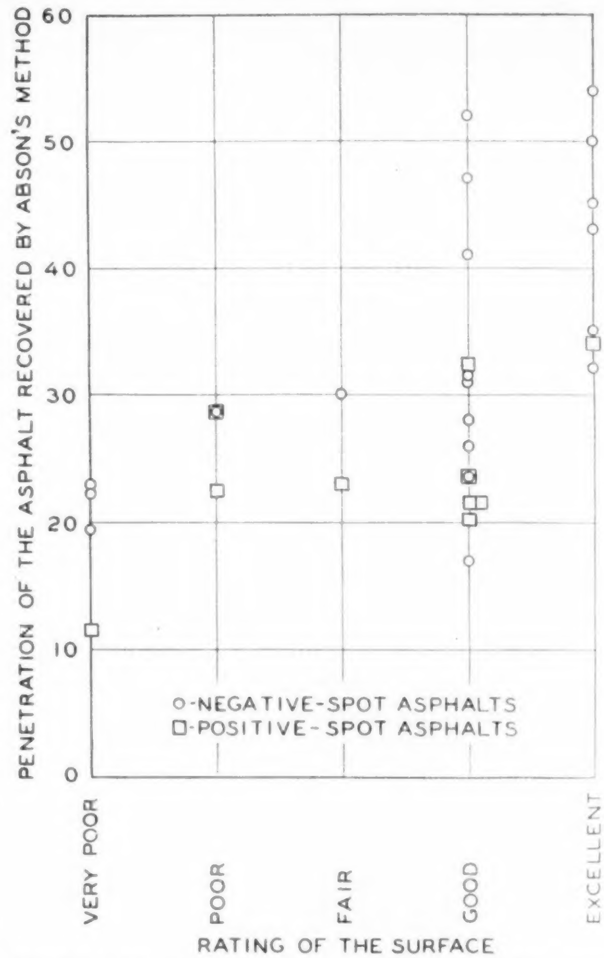

FIGURE 9.—RELATION OF SURFACE CONDITION TO PENETRATION OF THE RECOVERED ASPHALT. (ALL SAMPLES TAKEN WHERE THE BASE WAS POOR OR VERY POOR HAVE BEEN OMITTED.)

reasonably be expected to remain in good to excellent condition as long as the 50–60 penetration asphalt used retains as much as 57 or perhaps 60 percent of its original penetration. This corresponds to an actual penetration of about 30 on the recovered asphalt (see fig. 9).

It does not follow that unsatisfactory pavement conditions will result as soon as the retained penetration falls below 57 percent because nine of the pavements classified as good ranged from 34 to 56 percent in retained penetration, indicating the influence of other favorable factors; but it seems safe to say that unsatisfactory surface conditions are more than likely to develop when the retained penetration of the grade of asphalt used in these pavements falls to the vicinity of 40 percent or to an actual penetration of perhaps 20 to 22.

Figure 11 shows the relation of surface condition to the ductility of the recovered asphalt. The grouping of the points in the various condition classes is very similar to that shown in the previous figure although the numerical values are, of course, different. Reference to this figure shows that only good or excellent surface conditions were observed on pavements in which the ductility of the recovered asphalt proved to be 13 centimeters or more, provided the base conditions were average or better, and that only one unsatisfactory

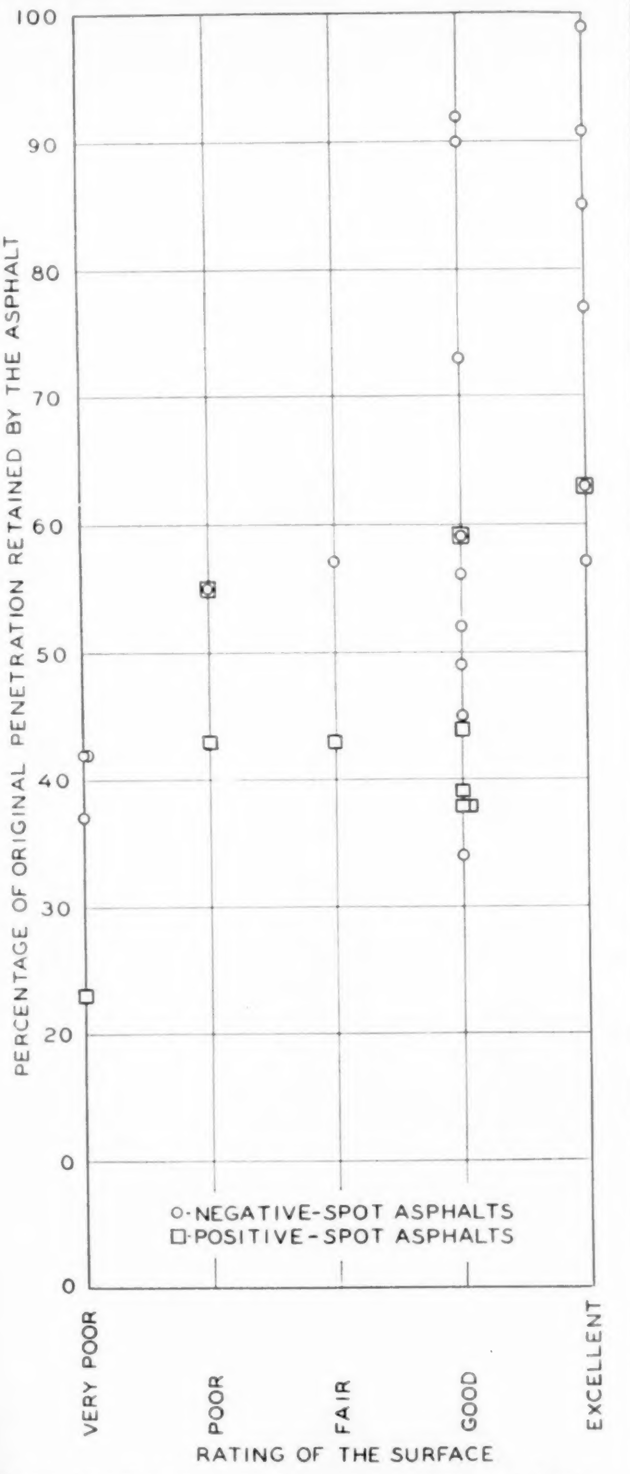

FIGURE 10.—RELATION OF SURFACE CONDITION TO PERCENTAGE OF ORIGINAL PENETRATION RETAINED BY THE ASPHALT. (ALL SAMPLES TAKEN WHERE THE BASE WAS POOR OR VERY POOR HAVE BEEN OMITTED.)

pavement was found in which the retained ductility was appreciably more than 10 centimeters. On the other hand, more than half the pavements in which the ductility of the recovered asphalt was 10 or less were in very poor to fair (average) condition.

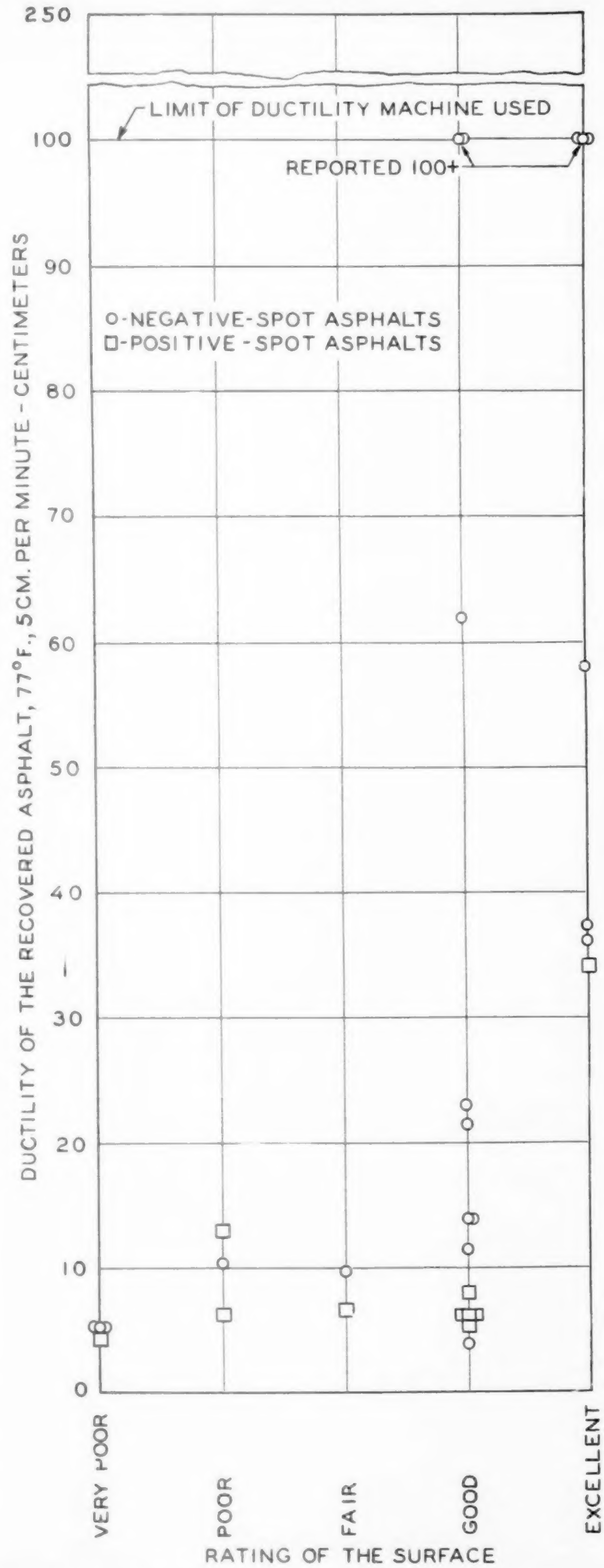

FIGURE 11.—RELATION OF SURFACE CONDITION TO DUCTILITY OF THE RECOVERED ASPHALT. (ALL SAMPLES TAKEN WHERE THE BASE WAS POOR OR VERY POOR HAVE BEEN OMITTED.)

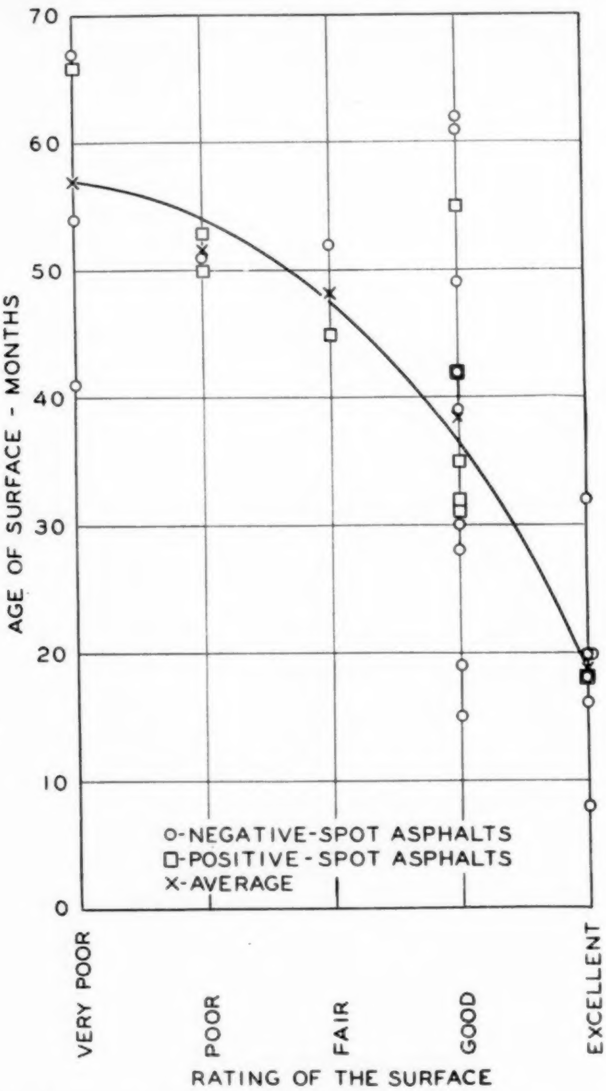

FIGURE 12.—RELATION OF SURFACE CONDITION TO AGE. (ALL SAMPLES TAKEN WHERE THE BASE WAS POOR OR VERY POOR HAVE BEEN OMITTED.)

BETTER SECTIONS HAD HIGHER RETENTION OF ORIGINAL PENETRATION AND DUCTILITY

In the analysis based on the limited number of tests made by the Public Roads laboratory (see table 7) the good and excellent surfaces were grouped together as satisfactory pavements and the poor and very poor were grouped as unsatisfactory. No samples from intermediate, or fair, surfaces were tested by this laboratory. On the basis of percentage of penetration retained, these two groups are clearly divided at 55 percent. Of the samples for which the penetration of the recovered asphalt was determined, all but two of those representing satisfactory surfaces contained asphalts that had retained more than 55 percent of their original penetration and all those that represented unsatisfactory surfaces showed retentions ranging downward from 55 percent. On the basis of residual ductility, a fairly good separation was obtained at a ductility of 10 centimeters. Eight out of ten samples from satisfactory surfaces contained asphalts having ductilities above 10 centimeters and all the asphalts tested from unsatisfactory pavements had ductilities of less than 10 centimeters.

Tests were made on the asphalt from both the surfacing and binder course of four samples to determine whether the character of the asphalt showed more alteration near the exposed surface than at a deeper level. The results of these tests are shown in table 8. As would be expected, these asphalts showed consistently greater changes in the wearing course than in the binder course. The amount of hardening at the higher level was the greater in all cases and the loss of ductility was greater for three out of the four samples for which the comparison was made.

The factor of age naturally had an important effect on the condition of the wearing courses. The relation of surface condition to age is shown in figure 12. None of the poor or very poor surfaces were less than 40 months old and only one of the excellent pavements was as much as 32 months old. However, the age of the surfaces described as good ranged from 15 to 62 months, another indication that no one factor could be used to account for the condition of the pavement.

The roller stability test, although made on only a limited number of samples (see table 7) produced valuable information. The roller stability values for eight samples of satisfactory pavement ranged from 12 to 89, indicating that the mixtures were still plastic.

The values for five out of six samples of unsatisfactory pavement ranged from 109 upward to 478, indicating that the pavements were becoming hard and showing a tendency toward brittleness. The other one of these six samples showed the extremely low stability of 4, indicating a very soft plastic condition. Although this pavement had not actually developed any rutting or corrugation, it is believed that its stability was dangerously low. Two samples from unsatisfactory pavements were too brittle and badly cracked to permit the sawing of specimens for the roller stability test.

It is believed that the magnitude of the roller stability values, indicating the dividing line between satisfactory and unsatisfactory pavements, may vary considerably for various types of surfacing mixtures and that, because of this probable variation, the figures given should be considered as applicable only to these or similar bituminous concrete wearing course mixtures containing little or no mineral filler.

EFFECT OF AGGREGATE GRADING STUDIED

Although this investigation was primarily concerned with the behavior of the asphalt rather than the aggregate, sieve analyses were made on the extracted aggregates from all the samples tested in the Public Roads laboratory, and vibratory compaction tests[4] were made on all but two of the aggregates. The results of these tests are shown in table 9.

The vibratory compaction tests indicated that all but 1 of the 20 mixtures tested contained sufficient or more than sufficient asphalt to fill the aggregate voids if the aggregate were compacted to its maximum obtainable density. The use of such an amount of asphalt as to produce up to 4½ percent of overfilling on the basis of the vibratory compaction tests (table 9) did not impair the stability of the surfaces as evidenced by their freedom from ruts or corrugations. It is, therefore, believed that in cases where little or no overfilling was indicated by the vibratory compaction tests some additional asphalt would not have impaired the

[4] Apparatus and method of test described by J. T. Pauls and J. F. Goode in PUBLIC ROADS, Vol. 20, No. 3, May 1939, page 55.

stability and might have been beneficial in providing better sealing.

Comparison of the aggregate densities in the pavements with the densities obtained by vibrating the dry aggregates indicated that, in several cases, additional compaction probably could have been obtained in the pavement if the limits of compactibility of the mixtures had been available as a basis for judging when sufficient rolling had been done. In other cases, the high densities of the pavement samples (see table 9, column 2) corresponding, in the case of sample 15–B, to 149 pounds per cubic foot or slightly more than 4,000 pounds per cubic yard, indicated that about the maximum practical density had been attained.[5]

An outstanding characteristic of the aggregates in most of these bituminous concrete surfacing mixtures was their low dust content and the fact that, with these low dust contents, most of the dry aggregates were capable of being compacted to aggregate densities of 85 to 90 percent, corresponding to aggregate void contents of 10 to 15 percent.

These highly compactible aggregates were produced by combining in carefully regulated proportions various sizes of crushed stone or slag with artificial or local natural sand without the addition of any filler material. The combined effect of low dust content and high density obtained by interlocking of the stone fragments accounts for the uniformly satisfactory stability of the mixtures in service. Such relatively harsh mixtures have the great advantage of high resistance to shoving even when not fully compacted and, because of the absence of filler material, are easily mixed. For this reason, attention could well be given to the advisability of permitting reduction of both the mixing temperature and mixing time when this type of surfacing aggregate is available.

Mixtures prepared with these harsh aggregates require special care in laying and finishing to prevent segregation, but experience has proven conclusively that uniform appearing, smooth-riding pavements can be built with them. In addition to having generally high stability, these pavements usually show either a typical sandpaper or a mosaic, nonskid surface texture depending upon their age and the amount and type of traffic carried.

SUMMARY

As indicated by the data obtained in this investigation, the performance of the pavements was influenced by so many variable factors that it is impossible to draw positive conclusions or to set up definite recommendations based on the data. However, the data do show certain trends that merit attention and suggest further investigation.

1. The design of the surfacing mixtures, as regards grading of the aggregate and quantity of asphalt used, appears to have been excellent as does the technique employed in constructing and finishing the wearing courses. The data indicate that only in rare instances was insufficient asphalt used or compaction short of a practical maximum obtained. In all cases, sufficient stability for the service required was obtained and the riding quality of the surfaces was generally excellent.

2. The type and condition of the bases had a very important bearing on the behavior of the surfaces. Obviously, no amount of care in the design, construction, and maintenance of the surfacing could be expected to compensate for failure of the base to furnish ample support. This investigation was not undertaken to determine what was wrong with the bases, but the effect of base conditions had to be considered in order to arrive at a fair evaluation of the effects of other factors.

3. The character of the recovered asphalt, as judged by the Oliensis spot test, appears to have some bearing on the pavement condition. As a group, the average and poorer pavements on average or better bases contained 5 negative-spot and 4 positive-spot asphalts, while among the good and excellent pavements there were 15 negative-spot as compared to only 6 positive-spot materials. Thus the negative-spot asphalts were fairly definitely associated with satisfactory pavement behavior. As shown in figure 5, the positive-spot asphalts appeared to be somewhat more susceptible to the changes evidenced by hardening than those that showed a negative reaction to the spot test.

The data appear to show some superiority for the negative-spot asphalts extracted from the pavement samples. However, it is not known whether or not any of the asphalts were positive at the time the paving mixtures were prepared.

4. The data indicate that the drastic changes in the asphalt that were found to result from normal mixing operations probably resulted in the loss of many months of satisfactory pavement service.

It has been shown that both hardening and loss of ductility appear to continue throughout the life of the pavement. It has also been shown that, for the 50–60 penetration asphalt involved in this investigation, satisfactory service is quite likely not to continue after the penetration has fallen appreciably below 57 percent of the original or to an actual penetration of something less than 30 while the corresponding critical ductility appears to be about 10 or perhaps 13 centimeters. It seems logical to conclude, therefore, that any hardening or reduction in ductility that occurs during mixing must shorten the life of the pavement by about the number of months that would be required to produce the same changes under service conditions. Thus, the mixing losses assume considerable importance because they add materially to the annual pavement costs.

Since oven loss tests on penetration grade asphalts generally produce little or no weight loss at 325° F., a temperature comparable to the mixing temperatures of 275° to 375° F. employed in Ohio, it appears that the changes that occur in the asphalt during mixing must be largely chemical in nature. Therefore, it is impossible to judge, from the data presented, whether the percentage penetration loss or the actual residual penetration is the better index of deterioration of the asphalt. Certainly the critical values suggested for either, as appropriate for 50–60 penetration asphalt, should not be applied indiscriminately to other grades without previous investigation.

5. Alterations in the asphalt caused by mixing appear to depend upon two factors, namely, the susceptibility of the asphalt to alteration and the conditions and time involved in the mixing operation.

It would be unreasonable to expect that asphalts of such low susceptibility to hardening could be produced that they could not be damaged by oxidation, overheating, or excessive mixing. Furthermore, it is

[5] Subsequent investigations made by the Ohio Department of Highways, comparing the densities of newly laid pavements with the respective densities after several months' service, indicate that ultimate density is seldom obtained during construction even under the most stringent rolling requirements. The tendency for the aggregate particles to rearrange under traffic and to approach the vibrated aggregate densities increases with the use of softer asphalts.

unlikely that improvements in plant design and management can entirely eliminate hardening, particularly for the asphalts that are highly susceptible to alteration. It does seem reasonable to expect that both the character of the asphalt and the design and management of mixing plants can be improved so that alteration of the asphalt will be very materially reduced and pavement life correspondingly increased.

It has been pointed out previously [6] that specification requirements seeking to control both the asphalt furnished and the manipulation to which it is subjected, by establishing minimum requirements that must be met by the asphalt extracted from the finished pavement, result in dividing the responsibility between the producer who furnishes the asphalt and the contractor who uses it. The specifications should accomplish two distinct objectives: (1) They should assure that the asphalt, as delivered, is resistant to alteration, and (2) they should assure that the asphalt shall not be unduly altered by the contractor.

To control the quality of the asphalt delivered, insofar as its resistance to alteration is concerned, a clause should be inserted in the material section of the specifications providing that the asphalt shall meet certain minimum requirements in a suitable laboratory test. This will necessitate the development of a laboratory test that, when properly correlated with mixing plant data, will furnish a dependable index of the resistance of the asphalt to the alterations evidenced by changes in penetration and ductility. Because of the large number of samples handled daily by many laboratories during the construction season, the test should be as simple as possible. A number of laboratories are now working on this problem.

To assure protection of the asphalt through high-type mixing plant equipment and management, a clause in the construction section of the specifications might be justified to provide that the asphalt extracted from the freshly laid pavement shall meet suitable minimum requirements for penetration and ductility. Assuming that the asphalt, as delivered, had shown satisfactory qualities in the test for resistance to alteration, the construction or protection clause would then make the contractor definitely responsible for any excessive alteration of the asphalt during manipulation.

Improvement of mixing plant management involves the modification of present practices to take full advantage of relatively recent developments in the design of the mixtures and of improvements in equipment and methods of construction.

As noted in the first part of this report, the early design of the fine aggregate type of bituminous concrete required the addition to the aggregate of a considerable portion of mineral dust or filler. Under the present practice in Ohio, the mixtures contain only such dust as occurs naturally in the crushed aggregate and the natural or artificial sand. Field mixing tests have indicated that some of these aggregates can be satisfactorily coated with asphalt in less than 30 seconds of wet mixing as compared to the 45 or more seconds quite generally specified for mixtures to which dust is added.

The mixing temperatures required in early specifications were necessarily high enough to provide sufficient heat for rolling after such time-consuming operations as hauling the mixture to the job in slow conveyances and laying it by hand. With modern hauling and spreading equipment, heat losses between the plant and the pavement are considerably reduced. It is also significant that a somewhat cooler mixture can be handled satisfactorily by a mechanical spreader that can be finished by hand raking.

In general, the tendency has been to retain in present day specifications both the mixing times and the mixing temperatures dictated by the less favorable considerations of early design and construction methods. The use of lower mixing temperatures or shorter periods of mixing or both, when possible, should result in reduced hardening and loss of ductility.

Attention has been directed to what are believed to be reasonable and feasible measures for improving specifications and mixing-plant management. There remains the possibility of improving the design of mixing equipment further to protect the asphalt from the damaging effects of exposing it to the air at high temperatures and in thin films as is now the normal practice.

6. Protection of the asphalt against weathering changes after it is in the pavement is a third means of prolonging satisfactory service. Just how far weathering in the pavement can be reduced is not predicted but consistent attainment of all the conditions tending to retard weathering should be of material benefit. These include the provision of both surface and sub-base drainage to prevent the entrance of moisture into the mixture, the use of densely graded aggregates with sufficient asphalt to fill essentially all the pore spaces in the aggregate at optimum field compaction and, finally, the definite attainment of optimum compaction during construction.

[6] Needed Research on Asphalts, by E. F. Kelley. Proceedings Highway Research Board, 1935, p. 264.

(Continued from p. 128)

watchmen in protecting grade crossings. The computed hazard index of practically every crossing at which gates had been installed or a watchman employed was lower than the index of other crossings in the same assigned priority group. It is possible, however, that a majority of the committee desired to eliminate as many as possible of the crossings protected by gates or watchmen and therefore, consciously or unconsciously, assigned a higher priority to these locations than if rating had been by means of the mathematical formula. A few of the crossings, such as the first and third in the first priority group, were actually considered as one project, which increased the hazard of the combination above that of the projects with a single site and was a factor in their joint selection.

ADDITIONAL FACTORS CONSIDERED IN OTHER FORMULAS

The plan of rating all crossings which has been used by the Utah and Idaho Highway Planning Surveys includes a good example of an approximate formula which, although its coefficients and weights are based on judgment, apparently produces a reasonably satisfactory rating. More detailed information than is generally available in other States was collected and used in the development of the priority ratings. The formula, though based on earlier studies made in

TABLE 2.—*Hazard rating of 25 rural crossings in Maryland which were grouped by the State in 5 priority divisions*

Priority group No.	Route No.	Highway traffic	Train traffic	Protection	Highway factor (H^a)	Train factor (T^b)	Protection factor (P^c)	I_s	K	I	Total I for group
1	Co. 870	654	109	Gates (24-hour)	3.01	2.03	2.56	3.06	−0.37	2.69	20.54
	Md. 434	2,908	73	Lights and bells	3.88	1.91	2.25	4.21	+3.15	7.36	
	Co. 874	780	109	Gates (24-hour)	3.11	2.03	2.56	3.16	−.23	2.93	
	Md. 202	1,224	107	Gates (24-hour)	3.34	2.02	2.56	3.37	+.12	3.49	
	Co. 872	1,090	76	Lights and bells	3.25	1.92	2.25	3.55	+.52	4.07	
2	Md. 30	2,537	12	Bells	3.78	1.45	1.78	3.94	+1.96	5.90	17.03
	Md. 175	733	73	Lights and bells	3.07	1.91	2.25	3.34	+.06	3.40	
	Md. 131	1,314	34	Gates (24-hour)	3.38	1.70	2.56	2.87	−.57	2.30	
	US 220	2,279	16	Flashing lights	3.71	1.52	2.18	3.32	+.02	3.34	
	Co. 102	467	34	Lights and bells	2.84	1.70	2.25	2.75	−.66	2.09	
3	Md. 64	1,476	17	Bells	3.46	1.53	1.78	3.80	+1.35	5.15	15.13
	Co. 406	758	45	Watchman (24-hour)	3.09	1.78	2.52	2.79	−.64	2.15	
	Co. 216	346	107	Watchman (16-hour)	2.70	2.02	2.43	2.87	−.57	2.30	
	US 11	2,592	18	Lights and bells	3.79	1.54	2.25	3.31	0	3.31	
	US 15	1,258	28	Watchman (24-hour)	3.35	1.66	2.52	2.83	−.61	2.22	
4	Md. 201	2,933	17	Flashing lights	3.88	1.53	2.18	3.48	+.36	3.84	13.80
	Md. 30	2,322	10	Lights and bells	3.72	1.42	2.25	3.01	−.43	2.58	
	Co. 323	251	73	Lights and bells	2.55	1.91	2.25	2.76	−.65	2.11	
	Co. 142A	179	107	Gates (16-hour)	2.39	2.02	2.47	2.50	−.78	1.72	
	US 13	1,302	6	Signs	3.37	1.30	1.65	3.39	+.16	3.55	
5	Md. 149	139	112	Gates (24-hour)	2.29	2.03	2.56	2.33	−.83	1.50	11.42
	Md. 36	2,078	11	Flashing lights	3.66	1.44	2.18	3.10	−.31	2.79	
	Md. 351	874	29	Lights and bells	3.16	1.66	2.25	2.98	−.45	2.53	
	US 219	802	35	Lights and bells	3.12	1.71	2.25	3.03	−.40	2.63	
	Co. 100	399	34	Lights and bells	2.77	1.70	2.25	2.67	−.70	1.97	

Illinois and Connecticut, includes some valuable additions.

The index of hazard used in Utah and Idaho is calculated from a formula that assumes that hazard to the public is a function of the volume of vehicular and railroad traffic and of the nature of these movements over the crossing and the physical conditions existing there. Factors for the various elements entering into the hazard of the crossings have been selected with which to weight the items in relation to their relative importance. These factors are substituted in the following formula:

$$\text{Hazard index } (HI) = VT\ (T_1+S+A+N+C+M)$$

where V=factor representing volume of vehicular traffic,
T=factor representing volume of train traffic,
T_1=train type and speed,
S=view factor,
A=intersection angle,
N=number of tracks,
C=highway alinement, and
M=special conditions.

It is probable that the outstanding addition made by the Utah and Idaho formula to previous grade crossing formulas is the item covering type and speed of train movement. It is contended in these States that the likelihood of inaccurate judgment on the part of a vehicle operator increases roughly in proportion to the train speed and the time that the train blocks the crossing. Certain types of trains can be better controlled than others and the probability of an accident varies in proportion to this control. Electric trains, for instance, are generally shorter and more controllable than steam trains. The new streamlined models, due to their high speed, reach a crossing from a distant point within the clear view of a crossing in a surprisingly short time and, since they require a considerable distance in which to come to a stop, they are generally more dangerous to highway traffic than other types of train movement. Information concerning the type and speed of trains should add considerably to the value of a priority rating based upon a hazard formula.

A study of grade crossing accidents in Oregon developed some interesting suggestions that appear to be well worth considering. It was concluded in this State that the general formula used by most States was unnecessarily complex. For example, the Oregon study indicated that road surface conditions, sight distance, angle of intersection, number of tracks, and alinement had little or no effect on the number of accidents. It was not contended that these factors did not affect accident hazard, but it was assumed that adverse conditions in these factors caused enough motorists to exercise special caution to balance the undesirable conditions to such a degree that no more accidents occurred at crossings with poor conditions than if these conditions were normal.

The following simple formula was used in Oregon to rate all crossings:

$$HI = VT_1\ (S_v+S_t)\ (1+A)$$

where HI=index of hazard,
V=average daily vehicular movements,
T_1=average daily train movements (weighted to take care of the greater probability of night accidents),
S_v=vehicular speed factor,
S_t=train speed factor, and
A=accident record.

The most interesting item introduced by the Oregon Highway Planning Survey is the inclusion of a factor concerning the traffic, both vehicular and train, during the hours of darkness. Their studies indicated that while traffic volume generally decreases after dark, the accident rate increases. This tendency was pronounced, and it was determined that motor vehicle and train movements at night in urban areas were potentially 3.0 times as dangerous as daylight movements, and in rural areas 1.8 times as dangerous as daylight movements. Records of traffic movement were carefully divided into day and night traffic and the night traffic given greater weight in accordance with their findings. This increase in accidents during the hours of darkness probably accounts for a large portion of the great increase in the rate of accident occurrence in the months of October, November, and December, when traffic volume is generally decreasing. The inclusion of some factor that gives greater weight to

traffic that moves during the hours of darkness seems logical.

ADDITIONAL DATA MIGHT ENABLE DEVELOPMENT OF AN IMPROVED FORMULA

It appears from the study that has been made that some additional information should be obtained concerning the accidents and the conditions that existed at the crossings at the time of their occurrence. Better estimates of the highway and railroad traffic for the day and hour of the accident would be helpful. More complete descriptions of the accidents and the possible causes contributing to them should be given instead of using such stock phrases as "failed to observe signal" or "carelessness of driver." Reports concerning the causes of accidents, prepared by a public official trained to observe the necessary conditions and details, would be preferable to reports required of railroad officials. It is probable that a comparatively small amount of more reliable and more representative data would make possible the development of a formula that would be considerably more reliable than the ones given in this article.

Regardless of the dependability of the computed hazard rating for any crossing or group of crossings, this index should be used only as one type of measure of the need of crossing elimination. In some locations where motor-vehicle traffic volume is very low, protection may be desirable to protect railroad property, especially fast-moving trains, from slow-moving trucks or other large vehicles that are a hazard to the train passengers, crew, and equipment. As many factors as can be obtained should be considered along with the hazard rating.

The plan developed by the Maryland Highway Planning Survey has been adopted by the planning surveys in several other States to aid in the selection of crossings for elimination and in the assignment of priority numbers to these crossings or to groups of crossings. In this plan data concerning the more important crossings, as measured by highway and railroad traffic, are tabulated. These tabulations are submitted to several engineers concerned, including railroad officials, and a rating for each crossing is requested. The several ratings assigned are then combined by scoring points for first choice, second choice, etc., and priority ratings thus obtained. When a sufficient number of crossings have been assigned priority numbers for elimination, the balance may be studied concerning their protection needs.

It is believed that the hazard rating computed from the formula described herein and the protection coefficients suggested will be of value when combined with other independent ratings. Any rating made by individuals, as suggested above, could be combined with one made by using the hazard formula outlined in this report. A priority listing made on the basis of exposure (railroad times highway traffic) as related to cost of elimination might also be included. The combination of these data in each State should point to certain crossings or groups of crossings that should be eliminated and to others that should have some type of protection or at which better protection should be provided.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF JULY 31, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 359,177	$ 178,600	14.9	$ 7,066,399	$ 3,507,095	243.5	$ 1,662,300	$ 826,300	39.1	$ 1,564,288
Arizona	152,929	109,520	6.0	1,451,225	1,009,728	65.3	802,198	540,370	21.0	1,192,106
Arkansas	1,930,539	872,713	20.0	1,350,981	673,944	48.6	536,750	268,137	30.2	537,294
California	15,000	15,000		9,318,812	4,992,774	129.7	2,558,467	1,352,096	58.6	2,551,115
Colorado	404,854	232,450	17.3	2,172,689	1,258,368	102.5	1,769,277	998,748	140.5	2,100,788
Connecticut	13,227	6,614		2,018,841	984,064	23.9	832,797	405,834	9.3	842,532
Delaware				959,800	471,598	22.8	333,402	166,701	11.7	962,473
Florida				1,171,020	613,349	58.5	1,901,171	918,996	15.9	2,799,519
Georgia	538,133	269,066	13.2	6,711,024	3,365,762	265.3	5,105,264	2,552,632	217.8	4,888,345
Idaho	357,080	220,045	26.9	1,586,648	979,124	74.7	420,248	244,352	25.0	1,421,879
Illinois	507,476	254,488	10.0	8,332,012	4,166,006	172.2	3,309,556	1,654,222	30.5	3,252,148
Indiana	997,764	498,882	12.3	7,388,703	3,450,336	122.5	1,570,056	751,828	21.2	1,479,575
Iowa	40,777	19,450	8.3	4,649,076	2,222,358	156.2	2,903,447	1,339,790	111.7	174,810
Kansas	205,217	102,556	6.8	6,156,751	3,120,495	325.8	3,072,508	1,356,142	153.3	3,678,301
Kentucky	479,860	244,280	16.4	4,973,065	2,364,847	125.7	4,846,796	2,383,140	109.3	1,036,210
Louisiana	655,635	327,796	15.8	2,175,129	1,079,147	46.2	2,568,556	1,259,086	56.3	3,032,294
Maine	386,500	193,250	13.6	1,831,746	937,197	22.0	468,930	234,465	7.9	458,266
Maryland	862,000	431,000	11.7	3,458,362	1,677,678	20.9	753,000	317,000	6.1	1,187,839
Massachusetts	168,361	83,769	3.8	4,080,919	2,060,960	25.5	985,544	488,569	7.9	2,813,321
Michigan	1,943,200	971,600	37.5	6,549,320	3,262,060	142.0	2,049,600	1,024,800	24.1	1,584,592
Minnesota	506,687	253,343	63.7	8,996,185	4,457,622	453.6	3,178,990	1,586,630	176.3	1,571,909
Mississippi	426,800	213,400	26.5	7,764,712	3,817,506	435.5	407,700	202,100	17.5	912,583
Missouri	879,972	439,986	36.5	10,522,093	5,093,754	225.4	4,724,130	1,644,523	104.1	3,116,709
Montana	671,893	379,185	40.0	2,699,251	1,530,117	115.0	935,390	531,862	64.9	3,675,154
Nebraska	82,603	41,301	9.3	5,887,428	2,964,095	582.8	2,033,270	1,016,635	194.5	2,429,227
Nevada	21,720	18,935	4.4	2,451,864	2,132,544	109.2	336,339	291,898	13.0	489,986
New Hampshire	93,165	46,120	1.9	784,811	391,593	9.7	481,115	228,877	7.0	820,247
New Jersey	1,046,050	523,025	10.0	4,842,632	2,421,236	32.7	44,810	22,405		1,738,880
New Mexico	208,323	125,577	7.7	1,342,345	838,645	72.3	178,498	115,416	25.8	1,856,148
New York	1,744,145	871,173	30.1	11,195,737	5,570,467	136.5	1,983,300	830,900	19.6	3,534,891
North Carolina	97,560	32,885	1.1	4,665,614	2,344,150	208.0	1,561,566	773,320	51.9	2,045,336
North Dakota	737,590	388,233	73.2	3,436,730	1,831,459	275.2	3,284,780	1,651,067	276.8	3,014,116
Ohio	380,195	190,197	2.9	17,865,818	8,780,051	146.1	1,823,190	719,270	14.2	3,508,304
Oklahoma	281,800	148,847	7.3	3,470,474	1,794,581	122.4	2,516,120	1,301,744	71.3	4,246,442
Oregon	274,571	167,510	19.4	4,296,805	2,307,856	89.6	886,315	405,110	16.1	609,763
Pennsylvania	846,738	423,369	15.4	13,435,596	6,612,059	107.4	3,254,985	1,578,355	33.8	2,408,649
Rhode Island	145,865	72,925	1.6	1,234,850	615,462	10.4	116,277	58,139		946,713
South Carolina	239,350	116,500	26.6	4,097,797	1,876,344	132.1	1,516,753	279,827	33.1	1,858,391
South Dakota	603,550	343,440	44.6	4,389,413	2,744,793	510.5	1,083,840	674,160	160.6	2,388,045
Tennessee	222,098	111,049	4.2	5,633,244	2,816,622	135.7	1,177,794	588,897	24.5	3,133,974
Texas	929,165	460,375	43.9	14,459,325	7,139,584	625.9	3,183,498	1,481,460	131.8	5,853,985
Utah	68,825	52,475	16.2	2,322,620	1,685,546	53.4	308,652	182,190	13.1	531,138
Vermont	136,537	67,759	2.9	1,308,575	649,480	31.2	534,806	267,403	15.5	76,512
Virginia	411,254	205,132	10.6	5,177,955	2,427,827	89.3	435,864	217,932	11.3	1,715,316
Washington	197,670	105,700	4.7	2,996,486	1,597,694	42.0	929,618	467,085	10.5	747,645
West Virginia	430,900	214,260	9.5	3,828,901	1,903,706	59.1	502,390	251,195	6.2	1,458,817
Wisconsin	420,997	208,730	12.8	3,152,374	1,566,878	117.4	4,311,734	1,796,563	128.0	2,964,300
Wyoming	37,683	24,086	10.6	1,561,022	990,771	151.8	452,932	246,929	46.4	1,089,062
District of Columbia	172,023	86,000	1.4	754,001	376,190	1.3				427,984
Hawaii	140,808	70,395	1.1	431,890	248,149	6.6	296,658	277,186	3.2	1,705,325
Puerto Rico				1,562,404	771,610	16.9	683,965	334,890	5.5	551,005
TOTALS	22,474,266	11,432,991	774.6	239,971,474	122,495,281	7,298.8	81,615,146	39,107,176	2,773.9	98,984,251

STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

AS OF JULY 31, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 227,842	$ 113,918	6.9	$ 1,218,214	$ 611,541	55.7	$ 317,800	$ 153,230	26.2	$ 413,108
Arizona	67,371	48,972	4.5	135,027	100,270	.8	53,969	39,230	8.7	357,900
Arkansas	82,198	40,837	7.8	330,456	164,637	24.8	288,925	144,423	14.8	164,875
California	17,000	17,000		1,487,878	998,288	22.3	129,976	74,930	3.6	448,063
Colorado	63,585	35,343	3.7	88,061	39,905	17.0	117,948	42,994	2.1	281,543
Connecticut	105,456	49,907	1.8	192,579	86,423	4.3	249,242	109,263	4.8	80,871
Delaware				262,653	128,712	7.3	148,223	59,293	8.8	158,438
Florida	112,906	56,453	4.4	1,026,052	512,576	7.4				251,187
Georgia	31,541	15,771	4.9	957,205	555,952	54.4	1,095,750	547,875	102.8	711,128
Idaho	106,084	62,208	8.7	189,796	116,707	10.4	40,937	7,402	1.2	235,432
Illinois	42,000	21,000	3.7	1,692,710	846,355	75.7	261,500	118,050	10.2	361,191
Indiana				1,333,305	633,496	71.7	406,400	203,200	14.8	598,434
Iowa	110,705	52,640	34.3	557,527	245,818	124.3	67,726	31,705	6.8	428,933
Kansas				1,558,781	786,561	84.5	1,117,004	556,006	132.1	694,943
Kentucky	188,419	49,500	7.0	1,103,256	275,888	49.5	878,089	232,224	61.6	204,713
Louisiana				564,708	230,289	20.6	289,362	138,761	21.5	446,100
Maine				14,200	7,100	.8				159,720
Maryland				689,000	344,325	19.6	113,000	56,500	2.9	199,221
Massachusetts	30,398	15,199	.4	764,718	398,912	13.7				362,739
Michigan	87,200	43,600	6.8	1,265,960	632,980	66.2	309,800	152,900	22.6	419,754
Minnesota	88,594	44,297	12.7	1,367,275	691,445	149.5	866,816	433,008	102.6	386,982
Mississippi				1,134,994	557,312	61.3	343,561	166,231	9.1	485,642
Missouri	55,672	27,836	4.5	491,716	233,275	36.7	488,802	203,003	75.9	787,133
Montana	29,368	16,572	1.1	394,715	224,332	49.6	41,962	23,859	10.3	659,491
Nebraska	30,772	15,386	5.0	671,127	340,841	67.8	77,778	38,889	17.6	384,779
Nevada				122,442	106,515	12.8	187,489	162,927	15.8	65,098
New Hampshire				155,106	76,532	4.7	187,417	92,808	3.5	88,885
New Jersey				499,182	261,105	11.0	472,020	231,875	17.4	354,146
New Mexico	51,831	32,472	11.5	374,625	236,375	31.1	64,258	41,550	3.6	178,277
New York	222,320	111,160	3.8	1,161,914	583,655	28.0	203,000	101,500	3.2	594,650
North Carolina	39,770	19,885	5.0	600,259	304,708	50.0	125,218	45,000	8.8	364,461
North Dakota				52,986	29,992	2.4	808,050	793,860	42.7	483,046
Ohio	262,720	131,360	7.1	1,860,560	977,855	55.5	452,870	210,500	4.8	846,492
Oklahoma	78,400	41,411	1.3	284,426	150,150	20.4	856,486	452,224	64.6	741,010
Oregon	16,615	10,140	3.2	567,153	289,503	41.3	211,366	96,830	21.3	190,785
Pennsylvania	385,828	192,914	7.4	1,961,267	969,567	37.7	160,564	80,282	2.9	41,831
Rhode Island	84,274	42,080	.9	126,824	66,911	1.7	3,920	1,960		63,989
South Carolina	18,217	7,500	5.6	626,450	241,666	38.0	353,000	135,124	11.5	164,848
South Dakota				25,302	15,768	9.0	1,153,880	1,053,460	120.8	489,674
Tennessee	27,640	13,820	.2	1,381,928	690,964	34.2	474,516	237,258	30.2	437,708
Texas	203,860	101,380	26.7	1,093,456	533,711	99.6	307,835	149,875	28.7	1,356,521
Utah	17,470	7,796	5.7	231,725	148,387	13.8				208,507
Vermont	34,027	17,013	1.2	2,192	1,096					91,346
Virginia	31,750	10,000	.6	474,190	231,352	17.0	202,000	82,152	2.5	383,586
Washington				420,865	244,139	20.3	145,651	39,700	6.4	222,924
West Virginia				704,324	351,549	26.2				320,571
Wisconsin	343,263	171,610	11.1	1,143,332	569,698	45.4	1,082,977	394,180	36.4	181,678
Wyoming	147,903	92,283	9.1	261,048	84,945	18.8	289,451	101,400	18.7	99,412
District of Columbia	56,011	28,000	.6	2,192	1,096		28,024	13,550	.3	74,394
Hawaii				1,096	1,096					250,559
Puerto Rico				231,364	112,855	10.6				134,597
TOTALS	3,499,010	1,757,263	219.2	33,858,121	17,045,130	1,725.4	15,472,562	8,050,991	1,105.1	18,111,315

U. S. GOVERNMENT PRINTING OFFICE: 1941

PUBLICATIONS of the PUBLIC ROADS ADMINISTRATION

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Agency and as the Agency does not sell publications, please send no remittance to the Federal Works Agency.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1932. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1933. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1934. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1935. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1936. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1937. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1938. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1939. 10 cents.

Work of the Public Roads Administration, 1940.

HOUSE DOCUMENT NO. 462

Part 1 . . . Nonuniformity of State Motor-Vehicle Traffic Laws. 15 cents.

Part 2 . . . Skilled Investigation at the Scene of the Accident Needed to Develop Causes. 10 cents.

Part 3 . . . Inadequacy of State Motor-Vehicle Accident Reporting. 10 cents.

Part 4 . . . Official Inspection of Vehicles. 10 cents.

Part 5 . . . Case Histories of Fatal Highway Accidents. 10 cents.

Part 6 . . . The Accident-Prone Driver. 10 cents.

MISCELLANEOUS PUBLICATIONS

No. 76MP . . The Results of Physical Tests of Road-Building Rock. 25 cents.

No. 191MP. . Roadside Improvement. 10 cents.

No. 272MP. . Construction of Private Driveways. 10 cents.

No. 279MP. . Bibliography on Highway Lighting. 5 cents.

Highway Accidents. 10 cents.

The Taxation of Motor Vehicles in 1932. 35 cents.

Guides to Traffic Safety. 10 cents.

An Economic and Statistical Analysis of Highway-Construction Expenditures. 15 cents.

Highway Bond Calculations. 10 cents.

Transition Curves for Highways. 60 cents.

Highways of History. 25 cents.

Specifications for Construction of Roads and Bridges in National Forests and National Parks. 1 dollar.

DEPARTMENT BULLETINS

No. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922. 15 cents.

No. 1486D . . Highway Bridge Location. 15 cents.

TECHNICAL BULLETINS

No. 55T . . . Highway Bridge Surveys. 20 cents.

No. 265T. . . Electrical Equipment on Movable Bridges. 35 cents.

Single copies of the following publications may be obtained from the Public Roads Administration upon request. They cannot be purchased from the Superintendent of Documents.

MISCELLANEOUS PUBLICATIONS

No. 296MP. . Bibliography on Highway Safety.

House Document No. 272 . . . Toll Roads and Free Roads.

Indexes to PUBLIC ROADS, volumes 6–8 and 10–20, inclusive.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

UNIFORM VEHICLE CODE

Act I.—Uniform Motor Vehicle Administration, Registration, Certificate of Title, and Antitheft Act.

Act II.—Uniform Motor Vehicle Operators' and Chauffeurs' License Act.

Act III.—Uniform Motor Vehicle Civil Liability Act.

Act IV.—Uniform Motor Vehicle Safety Responsibility Act.

Act V.—Uniform Act Regulating Traffic on Highways.

Model Traffic Ordinances.

A complete list of the publications of the Public Roads Administration, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to Public Roads Administration, Willard Bldg., Washington, D. C.

STATUS OF FEDERAL-AID GRADE CROSSING PROJECTS

AS OF JULY 31, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	NUMBER			Estimated Total Cost	Federal Aid	NUMBER			Estimated Total Cost	Federal Aid	NUMBER			
			Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise			Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise			Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama						$ 218,339	$ 216,539	3	3	3	$ 275,373	$ 275,151	5	2	5	$ 800,893
Arizona						168,266	168,266	1			29,350	29,350		1	2	208,296
Arkansas						452,612	452,283	5			173,273	171,563	1		4	336,347
California	$ 373,345	$ 188,129	1			1,315,838	1,309,865	9	1		23,290	23,290			8	1,473,769
Colorado	5,685	5,646				582,845	575,612	5			12,758	12,758	1			568,938
Connecticut	166,223	165,415	2								293,086	283,416		2		351,963
Delaware						94,135	94,135	1			697,074	508,721	3	1	1	51,500
Florida						341,563	340,574	4		5	564,570	560,314	4		34	709,591
Georgia	160,128	160,128	2	1		1,089,304	1,089,304	8	6	2	1,024,001	1,024,001	4	5	22	1,162,515
Idaho	11,301	11,301				216,402	207,730	2	1		120,444	120,444	2		4	252,590
Illinois	28,907	26,730			11	1,897,887	1,692,465	7	1	51	403,670	386,664	3		26	1,911,232
Indiana	2,033	2,033			2	787,687	775,200	6	1	6	195,859	190,150			47	832,885
Iowa						1,110,006	872,718	8	2	3	684,985	663,361	4	1	65	288,491
Kansas						383,757	383,757	8		2	424,799	424,484	3		10	955,756
Kentucky	87,515	87,515	2			996,297	995,297	6	1		147,955	141,842	2		1	352,675
Louisiana						454,657	454,657	6			449,979	448,812	5		1	766,047
Maine						113,072	113,072	1			278,011	278,011	1		1	115,569
Maryland	100,000	100,000	1			702,459	670,666	3	2	6	429,953	429,475	1		16	231,439
Massachusetts						435,901	425,263	2			1,408,925	1,407,670	6	3		908,141
Michigan	132,000	132,000				1,212,055	1,212,055	3	4	4	515,674	485,513	2		18	613,837
Minnesota	75,799	75,799		2		1,095,448	1,095,448	7	3		380,249	380,249	2	3	1	732,570
Mississippi	175,200	175,200	1			568,175	568,175	8			145,199	145,199	1	1	11	545,338
Missouri						2,034,922	1,579,502	6	4		59,161	59,161		1		1,289,828
Montana						174,019	174,019	2			65,416	65,416	1		2	464,383
Nebraska	112,950	112,950		1	2	1,006,679	1,006,679	17		6	201,067	201,067	6		17	139,173
Nevada						120,830	120,830	3			71,448	71,448	1		5	107,895
New Hampshire	63,682	62,862	2			144,098	144,098	1	1		162,246	161,946	3	1	2	203,156
New Jersey	214,360	214,360	2			978,013	852,463	4	1	1	356,760	316,805	1	2		802,451
New Mexico						2,560	2,560				259,103	252,068	3		1	403,805
New York	331,658	324,885		2		3,512,506	3,458,185	5	15		617,945	579,285		2		2,748,455
North Carolina	4,330	4,330			1	539,933	539,933	2	7	4	244,818	244,818	1		33	884,344
North Dakota	49,670	49,670	1			547,300	534,363	8			395,520	395,520	3			333,598
Ohio						2,410,587	2,379,544	11	1		1,896,627	1,591,430	7		7	1,059,082
Oklahoma	89,005	85,589	1		4	87,602	86,112	1		5	1,203,212	1,143,255	8		27	1,113,503
Oregon						420,835	357,222	5			10,523	10,523			5	390,976
Pennsylvania						3,724,763	3,690,554	22			1,273,167	1,266,570	8			1,587,188
Rhode Island						206,703	206,703		1							178,256
South Carolina	23,546	23,546			4	260,032	249,932	6	1	6	481,658	349,084	2	3	21	726,341
South Dakota	296,340	296,340	8			382,792	382,792	9			377,183	361,233	7		9	587,095
Tennessee	64,350	64,350	1	1		852,105	843,105	5	2		515,023	515,023	3	1		916,442
Texas	68,400	68,400	2			1,999,561	1,983,081	19			496,663	474,709	7		2	1,393,651
Utah	11,608	11,608			4	74,921	74,179	3		10	94,602	94,602			33	232,380
Vermont						257,986	257,986	2		3	3,297	3,297			1	50,478
Virginia						807,874	807,415	5	5		77,869	58,369	1		5	582,794
Washington						379,654	379,654	3	2		11,977	11,977			4	458,898
West Virginia						612,732	607,112	8		2	297,750	297,750	1	1	6	509,681
Wisconsin	10,624	10,624			2	870,371	840,387	5	2	7	177,335	177,335			39	1,156,114
Wyoming	163,685	163,685	1			316,421	316,420	4			5,322	5,322			5	290,375
District of Columbia						3,655	3,655				298,213	273,744		1		
Hawaii	192,574	192,567	2			212,708	212,193	2								181,412
Puerto Rico						742,969	735,496	10								337,988
TOTALS	3,015,418	2,815,662	29	7	30	37,921,836	36,539,255	271	67	126	18,332,382	17,372,195	113	31	501	33,300,124